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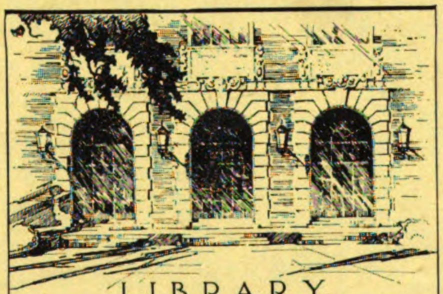

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Sir Charles Wheatstone, F.R.S.

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Engineer.

Pioneers of Electrical Communication

CHARLES WHEATSTONE—IV

By **ROLLO APPLEYARD**

European Engineering Department, International Standard Electric Corporation

IF from a list of names of famous men associated with the early development of electrical communication we exclude those immortalised in the designations of the electrical and magnetic units, the best known among the remainder is probably that of Charles Wheatstone; and if the telegraph and telephone engineers of the present generation were asked the reason for that electrician's undiminished popularity, a considerable proportion of them would attribute it, correctly enough, to "Wheatstone's Bridge." Nevertheless, he did not invent that device—on the contrary, he scrupulously assigned it to its true discoverer. Wheatstone's fame rests upon surer foundations; he was a pioneer in practical electrical communication, and a leader in the realms of qualitative and quantitative physical research. The memory of him lives—"not only for his discoveries and for the methods of investigation with which he had endowed science, but also by the recollection of his rare qualities of heart, the uprightness of his character, and the agreeable charm of his personal demeanor."

This last noble tribute from Jean-Baptiste Dumas, then Secretary of the French Academy of Science, uttered on the occasion of Wheatstone's death in Paris, scarcely more than half a century ago, has proved to be true beyond all that could have been imagined by his contemporaries. There are good reasons, therefore, for availing ourselves of any special opportunities that arise to renew or to extend acquaintance with the achievements and career of Charles Wheatstone. By the courtesy of the authorities at King's College, London, it has been possible recently to examine and to photograph some of the relics of his apparatus, and it is proposed here briefly to recall the part such apparatus played in the establishment of the principles of observation and measurement upon which modern electrical research is founded. The "King George III Museum" at King's College contains a collection that consists primarily of apparatus presented to the College in 1841 by Queen Victoria. It was originally brought together by George III at the Royal Observatory, Kew. To it has been added the "Wheatstone Collection" and the "General Collection." A catalogue of the whole exists, dated 1900, but there is no detailed account available of the various pieces of apparatus in the Museum.

Reference to researches to which the relics here illustrated relate, are to be found in innumerable volumes. If with these are included pamphlets of a controversial character, and articles in scientific and biographical works, the publications relating to Wheatstone become somewhat overwhelming. By judicious selection, however, the essential literature can be reduced to a few classic books and papers. So far as the scientific aspects of his achievements are concerned, the commemoration volume published in 1879 by the Physical Society of London, entitled "The Scientific Papers of Sir Charles Wheatstone" supplies all that is required for general knowledge of his discoveries and of his teaching. For an account of his work, and the work of his contemporaries, relating to telegraphy, attention must be directed to two papers read before The Institution of Civil Engineers on March 2, 1852—the first by Mr. Charles Coles Adley, and the second by Mr. Frederick Richard Window. These luminous contributions to the subject are both printed in Volume XI of the Proceedings of that Institution. To them must be added the obituary notice, written by one of his friends, which was printed in the Proceedings of the Royal Society, Volume XXIV, in 1876. In language that is at once appreciative and critical, it conveys a conception of the human side of Wheatstone, and leaves with us the impression of a man of high principle, of fine intelligence, and of invincible determination in research and its applications. What was the secret of his success? His modest early circumstances, and his immersion as a young man in commerce, could easily have made him a thriving

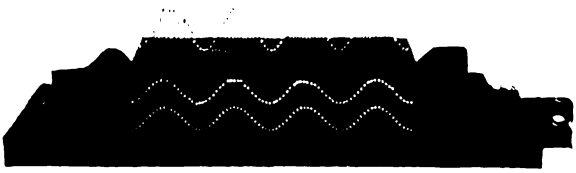


Figure 1—Wheatstone's Sine-wave Model

tradesman. But by what influences was he led along the path of research to the pinnacle of discovery?

Charles Wheatstone was born in February, 1802, in Gloucestershire. His father, a music-seller in the county-town, removed with his family in 1806 to 128 Pall Mall, London, where he taught the flute, and made and sold musical instruments. Charles, who had received a private-school education, showed early promise of mechanical ingenuity, and as he had clear notions of dynamical principles, he was not long in giving evidence of his capabilities. In 1821 he attracted attention by exhibiting an instrument the name and construction of which prove him to have possessed a sense of humor well calculated to dispel any priggish qualities that might have developed in such a clever youth. It was called "the enchanted lyre," and it was suspended from the ceiling by a "cord of the thickness of a goose-quill." The music appeared to proceed from a combined harp, pianoforte, and dulcimer. Wheatstone himself described it as an application of a general principle for conducting sound. A writer in the "Repository of Arts" of September, 1821, describing this instrument, foreshadowed modern broadcasting in a remarkable phrase, as follows: "Who knows but by this means the music of an opera performed at the King's Theatre may ere long be simultaneously enjoyed at Hanover Square Rooms, the City of London Tavern and even at the Horns Tavern at Kennington, the sound traveling, like gas, through snug conductors, from the main laboratory of harmony in the Haymarket to distant parts of the metropolis . . . perhaps words of speech may be susceptible of the same means of propagation."

It is noteworthy that this instrument was exhibited in the Adelaide Gallery, afterwards the scene of his experiments on the velocity of electricity and now part of a restaurant, to the east of St. Martin's Church, London.

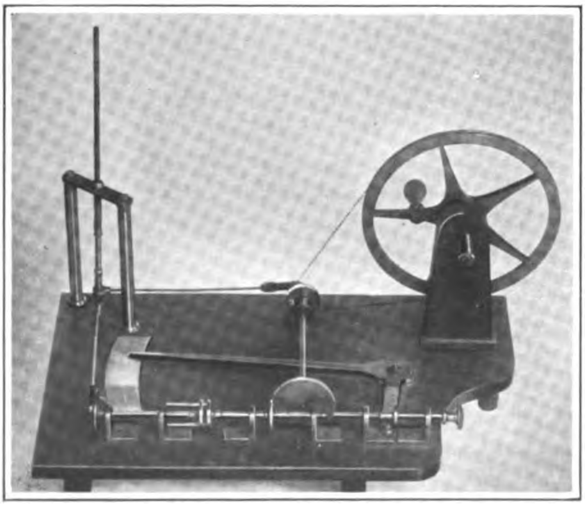


Figure 2—Adjustable Form of Kaleidophone

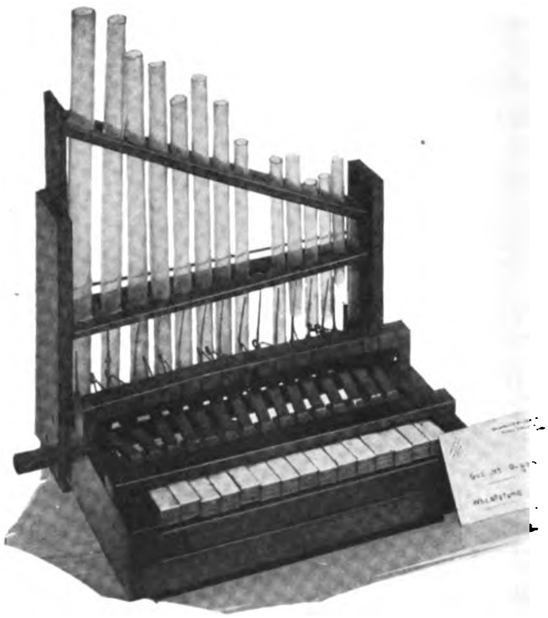


Figure 3—Gas-jet Organ

His early success with this instrument, the special features of which probably were the work of his own hands, must have been a source of great encouragement to him; for the inspirations of the physicist begin at the finger-tips, and the first victory never loses the charm that prompts renewed effort. There is evidence also that direction was given early to his scientific work by his comprehension of the importance of the undulatory theory of light propounded by Thomas Young (1773–1829). This was "the central thread of common sense" upon which the "pearls of analytical research" were strung. His collected papers indicate how firm was his grasp of the meaning of wave-motion, and his researches show with what ease he was able thereby to transfer his ideas from acoustics to optics, and from optics to electricity. To realise the measure of his early appreciation it should be remembered that his first scientific paper was published in 1823, at a time when, with his brother, he was engaged in the manufacture and sale of musical instruments in London. The reward of his subsequent labours was of a kind that gave him increased facilities for extending his researches. In 1834 he was appointed Professor of Experimental Philosophy at King's College, and in January, 1836, he was elected a Fellow of the Royal Society of London.

As an indication of the general trend of his ideas, there is his memoir on Chladni's figures, and his invention about the year 1828, of the "Kaleidophone"—a simple device for combining two harmonic motions. The Kaleidophone was a steel rod of oblong section, fitted rigidly at its lower end into a heavy base-block, and provided at the top with a white bead. When displaced and suddenly released, the bead traced a curved path—determined by the respective periods and phases of the two motions of the rectangular rod—similar to the outlines obtained with a modern cathode-ray oscillograph. Figure 1 shows his model representing wave-motion. It consists of a frame upon which is arranged a series of bent-wire levers terminated by white beads, and operated by sliding wooden templates cut to the form of waves. The lowest curve is permanently fixed; the upper two curves are modified in phase respectively by the movement of the sliders.

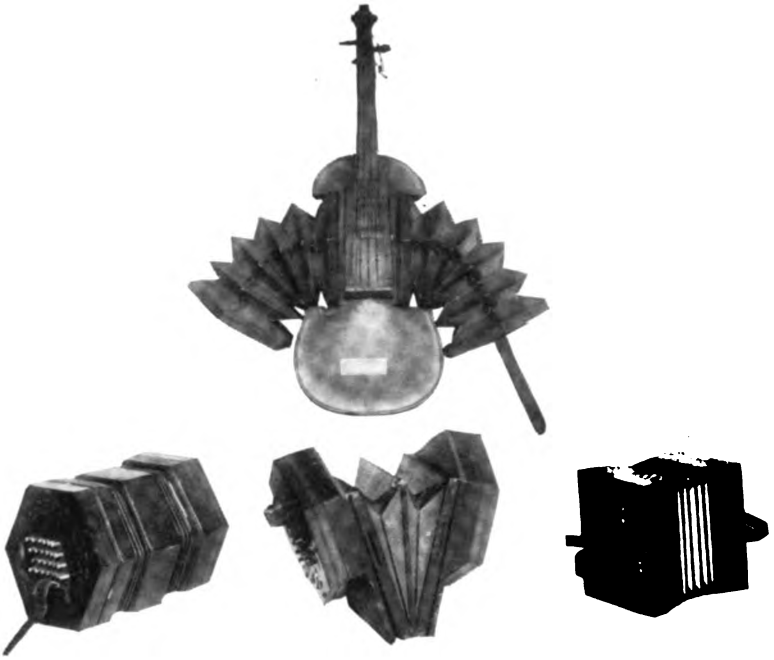


Figure 4—Concertinas and Concertina-fiddle

Figure 2 represents his adjustable form of Kaleidophone. It displays Wheatstone's skill in the design of mechanical gearing. The vertical rod is held near its middle point by a ball-and-socket joint. The driving-wheel causes the horizontal transverse shaft to rotate, and motion from this shaft is transferred through a friction-disc to a lateral shaft. The position of the driven-disc on this lateral shaft can be varied by turning a milled-head at the end of that shaft, and the difference in length is taken up by a sliding clutch. Harmonic motion is thus communicated through eccentrics to the lower end of the vertical rod.

In Figure 3 is seen Wheatstone's gas-jet organ, consisting of a group of glass tubes and gas-jets operated by a key-board. The apparatus has deteriorated with age, but there is no doubt that it consisted of a horizontal supply-pipe into which vertical jets were fitted, one to each glass tube, and that the glass tubes were free to move up or down. The keys, probably, were arranged to lift the pipes with respect to the jets to different heights, for "tuning" purposes. It may be supposed that this apparatus was associated with his work in 1828, with reference to resonance in air columns.

The next ten years of his life was a period of transition from research in acoustics to research in optics. Some of his triumphs up to this turning point in his career may be recalled by examining Figures 4 and 5. The English concertina was invented and patented by Charles Wheatstone in 1829. The instruments to the right and left in Figure 4 are marked "By Her Majesty's Letters Patent, Wheatstone & Co., Inventors, 20 Conduit Street, London." As Queen Victoria was not on the throne in 1829, these must not be regarded as Wheatstone's original concertinas. The concertina-fiddle, also shown in Figure 4, is provided with four longitudinal slots, near the bridge, one below each string, which were set into vibration after the manner of an aeolian harp. Figure 5 is an illustration of Wheatstone's original table-concertina, with foot-bellows and keys for finger manipulation. Figure 6 is his famous "Speaking Machine." This consists of hand-operated bellows on the left, and a complex resonator on the right. The right hand is placed over the trumpet shaped orifice or "mouth," with varying degrees of movement or pressure. Above the "mouth" are seen two tubular "nostrils," and below the mouthpiece is a small yielding resonator resembling bellows. It was a modification of De Kempelen's machine (1783). This subject was dealt with by Wheatstone at the British Association in 1835 in his paper "On the Attempts which have been made to imitate Human Speech by Mechanical Means." He wrote also a remarkable article on the history of such devices, in the London and Westminster Review of October, 1837, concluding with the prediction of Sir David Brewster: "We have no doubt that before another century is completed, a talking and a singing machine will be numbered among the conquests of science."

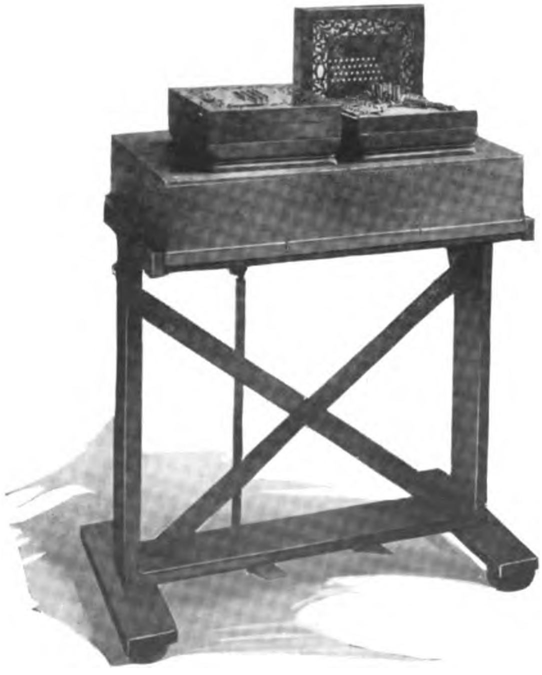


Figure 5—Table Concertina

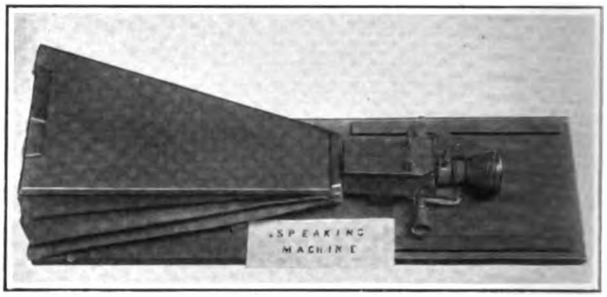


Figure 6—Speaking Machine

If there were no other record of his genius as a research worker than his paper written in 1835 on "The Prismatic Analysis of Electric Light," his fame would have been perpetuated; for he there announced the existence of bright lines in the spectrum emitted by the incandescent vapour of metals volatilised by the heat of an electric discharge—a mode of discriminating metallic bodies more readily than that of chemical examination. Thus he laid the foundations of spectrum analysis and was an early worker at emission phenomena.

Figure 7 is an example of Wheatstone's polar clock. It depends for its operation upon a discovery by Sir David Brewster that the plane of polarisation of the sky is always 90 degrees from the sun. The instrument contains a double-image prism and a thin plate of selenite enclosed in a tube placed parallel to the earth's axis. When the prism—which carries an index traversing a circular arc marked with the hours —is turned round until no colour is perceived, the index points to the time of day.

In 1838 he wrote on binocular vision and produced the reflecting stereoscope, embodying the principle that the notion of solidity in vision depends upon the mental superposition of two pictures of the same object in dissimilar perspectives. Brewster subsequently used for this purpose the wedge-shaped segments of large lenses, in which the lens and prism arrangement due also to Wheatstone were combined. In 1858 Wheatstone extended this research, and thereby wove the threads of his early achievements in acoustics and optics into the fabric of his later success in telegraphy. Wheatstone was knighted in 1868, following upon the success of his automatic telegraph.

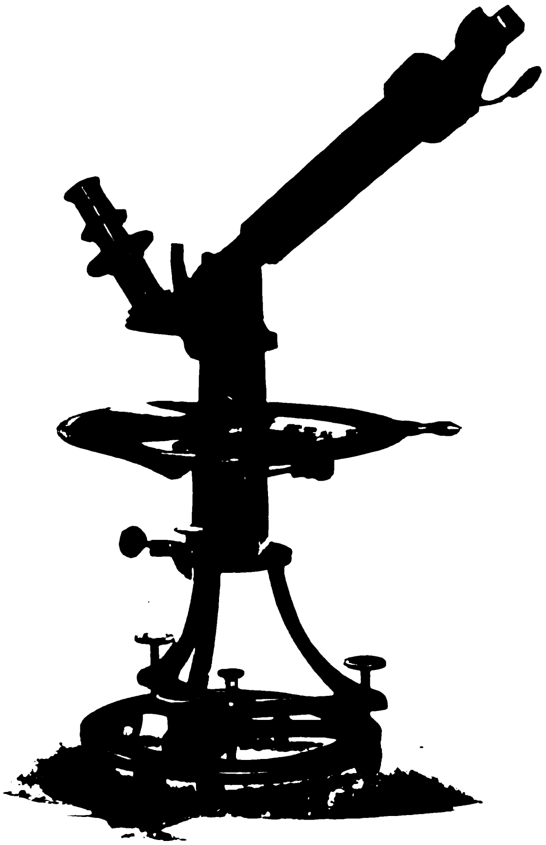


Figure 7—Polar Clock

"Wheatstone's Bridge" was invented by Samuel Hunter Christie (1784-1865). In his Bakerian Lecture (1843) Wheatstone described it as "The Differential Resistance Measurer," and he leaves no doubt for posterity to resolve concerning its orgin. He says: "Mr. Christie in his 'Experimental determination of the Laws of Magneto-Electric Induction' printed in the Philosophical Transactions of the Royal Society for 1833, has described a differential arrangement of which the principle is the same as that on which the instruments described in this section have been devised. To Mr. Christie must, therefore, be attributed the first idea of this useful and accurate method of measuring resistances."

Figure 8, which illustrates the original in the King's College Museum, is self-explanatory, except for the small lever attachment fitted to the upper middle terminal. This was used for making a fine adjustment of what we should now call the "variable arm." For this purpose the lever was swung round to left or right until it made contact with one or other of the wires of the two arms shown at the top of the illustration of the bridge, and the rotation was continued until balance was obtained.

In the introduction to his Bakerian Lecture Wheatstone stated that the instruments and processes he was about to describe were all founded on the principles established by Ohm "not yet generally understood and admitted, even by many persons engaged in original research." He proceeded to show the need for a

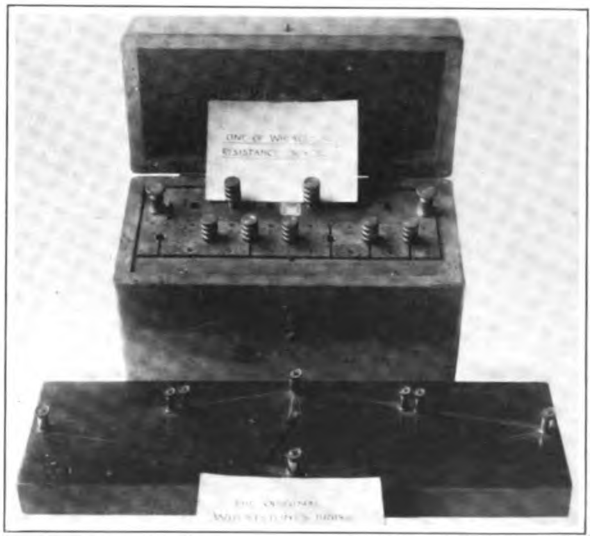


Figure 8—Wheatstone's Bridge and Resistance Box. The box is marked "Miles" near the first plug-hole on the left front.

correct standard of resistance; he adopted for his unit the resistance of a copper wire one foot in length and weighing 100 grains, and he stated the diameter as 0.071 of an inch. One of the original resistance boxes in the King's College Collection (Figure 8) is marked in "Miles"—thus adumbrating the Mile of Standard Cable. At the same time, he gave an account of "the differential galvanometer proposed by M. Becquerel." This, which in a later generation became an instrument of precision, in Wheatstone's day presented constructional difficulties. It is sufficient here to note its comparative antiquity, its supersession in 1843 by the bridge, and the association of the differential-galvanometer principle and the bridge principle as alternatives in the development of duplex telegraphy by Gintl (1853), Stearns, and others.

Wheatstone's generous and unqualified ascription to Christie of what today would be termed the "bridge principle," is more creditable and precious than any self-seeking claim could have been. The relics here illustrated serve to remind us how rapidly Christie's idea, Ohm's law, and Wheatstone's genius, conspired to produce a practical "bridge." To see the matter in true perspective, it is only necessary to turn to the original communication by Christie in the Philosophical Transactions of the Royal Society, Volume 123, 1833. He there describes an investigation to confirm what in modern language would be called the law of change of resistance with length, material, and cross-sectional area of wires, which had been clearly stated by Ohm six years earlier. He used two forms of apparatus.

In the first form, Figure 9, two wires of equal length and of different material, usually copper and iron, were wound differentially; i.e., in reversed directions, respectively, upon an iron core. The ends of the dissimilar wires were joined, and were connected to a galvanometer. The core was then placed across the poles of a large magnet. When the core was suddenly removed, the deflection, if any, of the galvanometer was observed.

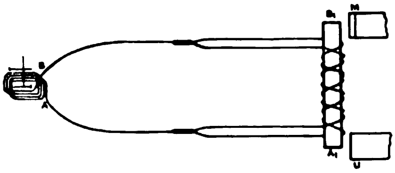


Figure 9—Christie's Differential Double Helix Resistance Balance

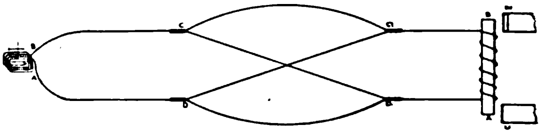


Figure 10—Christie's Single Helix Four-wire Resistance Balance

In the second form the arrangement was as represented in Figure 10. Here dissimilar wires were again connected in pairs, CC^1, CD^1, and DC^1, DD^1. In Christie's own words: "On the contact of the ends of the iron cylinder with the poles of the magnet being made or broken, a current of a certain intensity being excited in the helix round the iron cylinder, became, at the points C^1D^1, the source of currents in the copper and iron wires; at the points CD, equal facilities were afforded by the wires CB, DA, for the transmission of these opposing currents to the galvanometer, where consequently, their difference might be very accurately measured. Or viewing the subject in a somewhat different light, at the points C^1D^1, two routes are presented to the current excited in the wire of the helix, one through the copper wires, the other through the iron, and the effect at the galvanometer would measure the difference in the conductivity powers of the two metals."

Again, he states: "When I first made use of the arrangement which I have described, the subject being quite new to me, I was not aware of that employed by M. Becquerel. There is some similarity in the two, but the principles on which their application depends are very different. M. Becquerel's depends upon two equal currents, in separate wires, being equally diminished by two other currents, likewise in separate wires: mine, on the effect of a current in a single wire being counteracted by an equal and opposite current in the same wire, or that the opposite electricities neutralise each other, so that no current exists in the wire of the galvanometer. It appears to me that my arrangement combines the advantages of greater simplicity and greater accuracy."

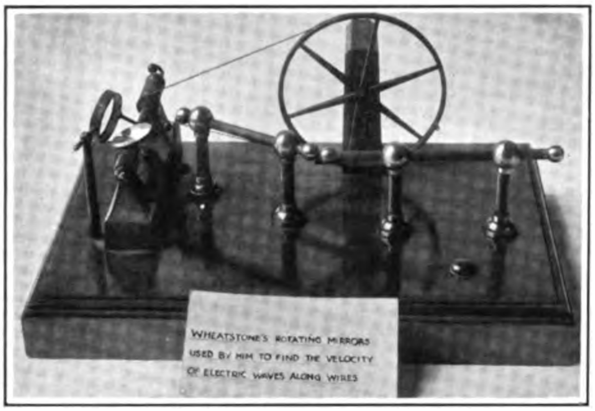

WHEATSTONE'S ROTATING MIRRORS
USED BY HIM TO FIND THE VELOCITY
OF ELECTRIC WAVES ALONG WIRES

Figure 11—Spark-gap and Rotating-mirror

The dynamical method of computation adopted by Christie should be examined in detail; it illustrates the difficulties encountered by those who, in Wheatstone's phrase, had "not yet generally understood" Ohm's law, in dealing with network problems.

Wheatstone's investigations of the "Velocity of Electricity and the Duration of Electric Light" are described in the Philosophical Transactions of the Royal Society of 1834. Examples of his original pieces of apparatus with their revolving mirror, from the King's College Collection, are illustrated in Figures 11 and 12. The story of his preliminary failures and of his constant determination to overcome all obstacles in this research must be read in detail to be appreciated. Some of his experiments on the time occupied by sparks to pass through insulated wire were carried out at "the Gallery in Adelaide Street." The greatest elongation he observed of the projected image of the spark was 24 degrees, corresponding to 1/24000 second, and for the velocity through the wire he obtained "288,000 miles in a second." In this trial the mirror rotated 800 times in a second. He also investigated the rate at which an electric wave travels through a wire, by suspending half a mile of copper wire in the vaults under King's College. Three interruptions of the circuit were made at three pairs of brass knobs. He repeated this research with four miles of wire.

With reference to these experiments Oliver Heaviside long afterwards pointed out (Electrical Papers, Part II, p. 395) that Wheatstone's result: "has not been supported by any later results, which are always less than the speed of light (even in a distortionless circuit). But a reference to Wheatstone's paper on the subject will show, first, that there was confessedly a good deal of guesswork; and next, that the repeated doubling of the wire on itself made the experiment, from a modern point of view, of too complex a theory to be examined in detail, and unsuitable as a test."

There is not space here to recount the wonderful story of Wheatstone's share in the development of telegraphy. The lamentable dispute with his partner, William Fothergill Cooke, will exemplify to all time the need for definite agreements between the principals in such enterprises, and the deplorable waste of energy, time, and happiness that results from personal friction. It must suffice to state with regard to the crowning achievement that Wheatstone's contemporary, De la Rive, said, "the philosopher who was the first to contribute by his labours, as ingenious as they were persevering, in giving electric telegraphy the practical character that it now possesses is undoubtedly Mr. Wheatstone." Of the combined efforts of the partners, it was declared by the late Willoughby Smith on the occasion of the Extraordinary General Meeting of the Society of Telegraph Engineers and of Electricians held in Paris during the Exposition Internationale d'Electricité, September 21, 1881, that "no account of a practical electric telegraph had been published

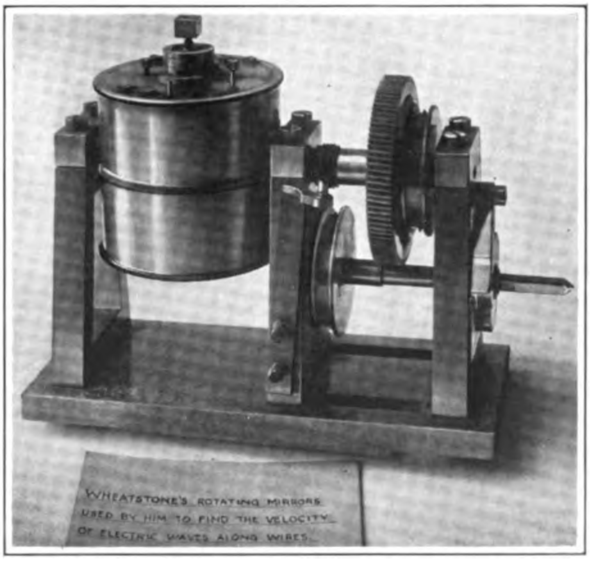

WHEATSTONE'S ROTATING MIRRORS
USED BY HIM TO FIND THE VELOCITY
OF ELECTRIC WAVES ALONG WIRES

Figure 12—Rotating-mirror

prior to the date of Messrs. Cooke's and Wheatstone's patent of June, 1837."

Among the illustrations of Wheatstone's apparatus may be seen the original of his Letter Showing instrument (Figures 13-A and 13-B). The maker was Ruhmkorff, Paris. Figure 14 shows Wheatstone's Relay. A V-shaped piece of metal attached to a magnetic needle is brought—when the needle is deflected—into contact with two mercury surfaces in a divided insulating cup. Figure 15 depicts Wheatstone's tape-puncher; Figure 16 Wheatstone's five-needle telegraph and Figure 17 Wheatstone's single-needle telegraph "sender" and "receiver."

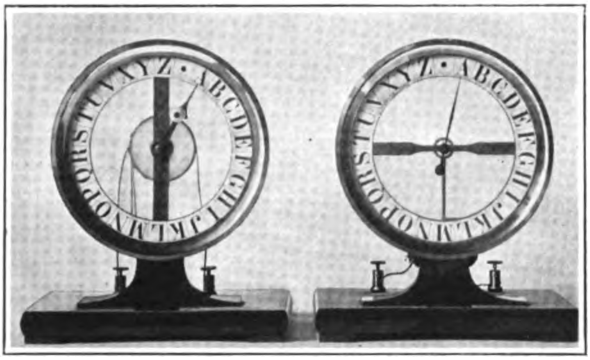


Figure 13-A—"Letter-showing Telegraph" (Front)

The tale of the five-needle electric telegraph (1837) is well told by Professor J. A. Fleming (Fifty years of Electricity). This telegraph was being worked between Fenchurch Street and Blackwall railway station, when three of the five dials broke down. The telegraph clerks, however, made up a code for working with the remaining two and the result was quite as good, if not better, than before. Thereafter one needle was found sufficient.

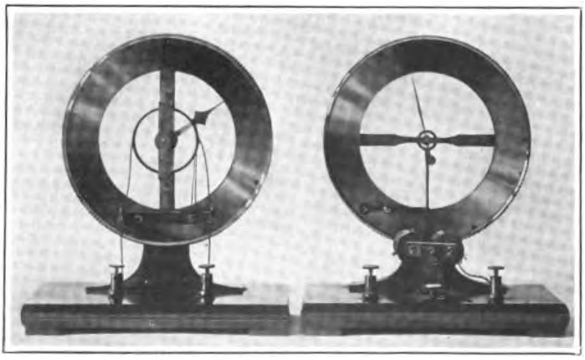


Figure 13-B—"Letter-showing Telegraph" (Back)

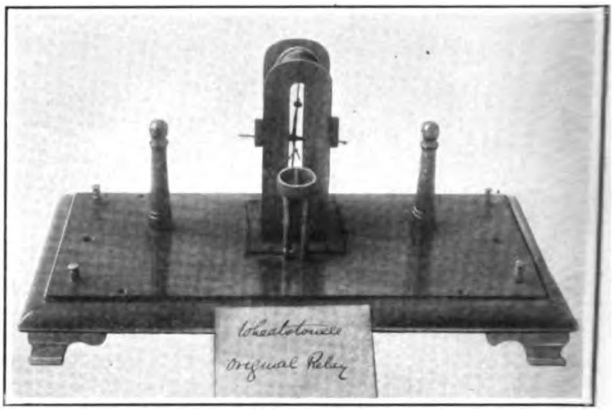


Figure 14—Original Relay

Figure 18 reminds us that Wheatstone contributed to the development of the dynamo. S. P. Thompson in his treatise on the dynamo has indicated the main features of Wheatstone's part in that work. Wheatstone began his improvements in 1841, with a machine in which for the first time the armature coils were so grouped as to give a really continuous current.

In 1856 C. W. Siemens took out a provisional patent for the shuttle-wound longitudinal armature, invented by Dr. Werner Siemens. On January 17, 1867, Dr. Werner Siemens described

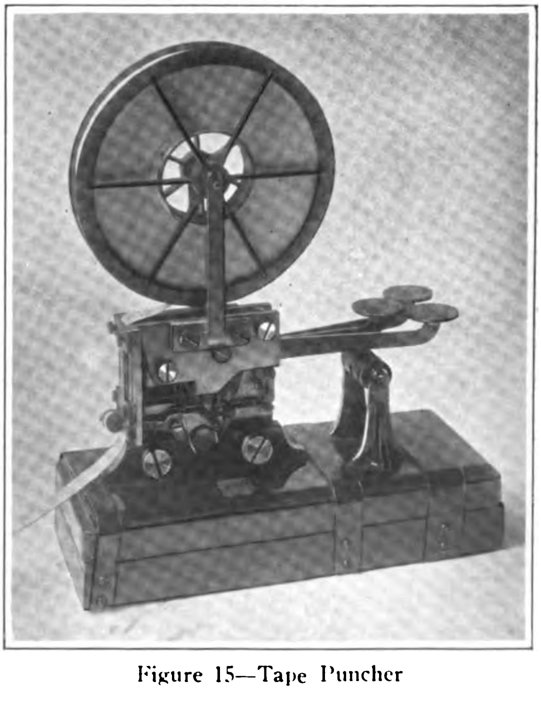


Figure 15—Tape Puncher

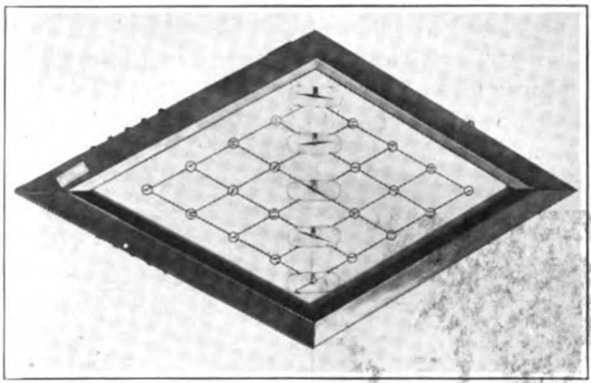


Figure 16—Five-needle Telegraph

a self-exciting dynamo in which the exciting coils were in the main circuit in series with the armature coil. On February 14, 1867, Wheatstone described to the Royal Society his invention of a similar machine in which the exciting coils were connected as a shunt. A self-exciting machine without permanent magnets had been constructed for Wheatstone by Stroh in the summer of 1866. In 1867 Ladd exhibited a self-exciting machine having two shuttle-wound armatures—a small one to excite the common field magnet, a large one to supply currents for electric light.

It is fitting that there should be found with Wheatstone's apparatus a tribute to the work of Henry. The precise history of the coils of copper strip, insulated with silk (Figure 19) cannot be ascertained, but the label, which has been attached to them for some years, declares them to have been used by Henry in his experiments on induced currents. Henry visited England in February, 1837, and met Wheatstone, Faraday, and Daniell at King's College. The three philosophers there exchanged ideas, and carried out experiments together. It is possible that these coils were used by Henry in this demonstration; but whatever their origin, they recall a fellowship that made history, and a meeting which Henry in subsequent years remembered with pleasure.

The relics include two photographs, one of Wheatstone, reproduced in the frontispiece, and the other (Figure 20) of Wheatstone in a group with his friends: Faraday, Huxley, Brewster and Tyndall. In Figure 20 Wheatstone is hold-

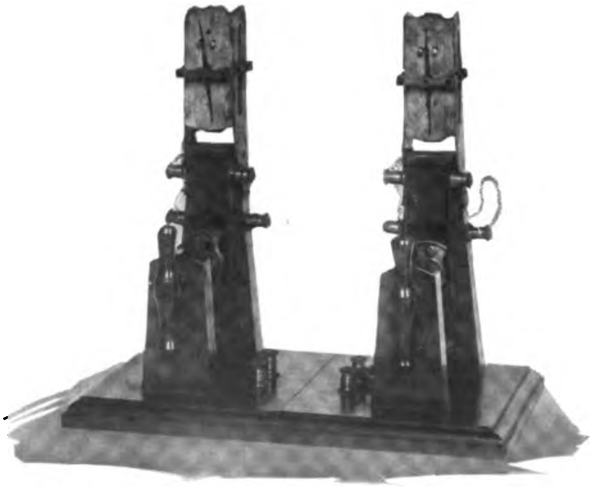


Figure 17—Single-needle Telegraph "Sender" and "Receiver"

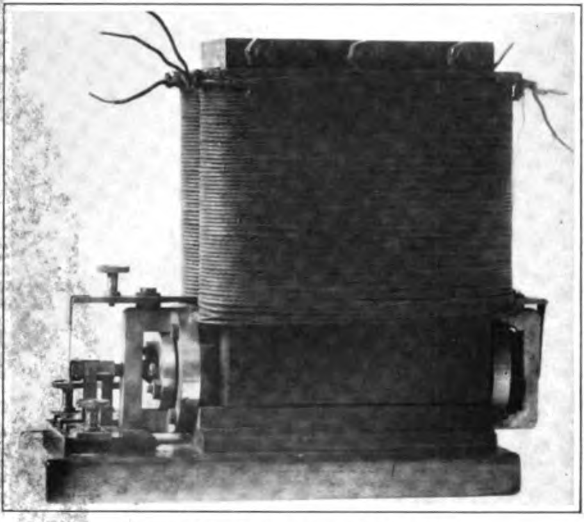


Figure 18—Wheatstone's Dynamo

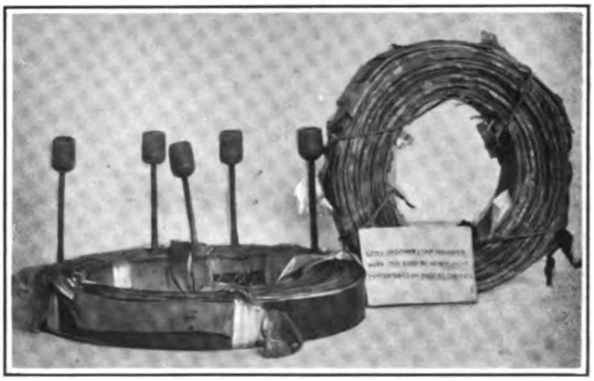


Figure 19—Coils of Copper Strip, Insulated with Silk, used by Henry in his experiments on induced currents

ing a Morse Key, while his companions are examining his Inkwriter, which is upon the table. The cell at the side of it appears to be a "Bunsen," but it may have been a "Daniell." It is appropriate that Wheatstone should be there amongst his peers: Faraday, the prince of experimenters; Huxley (1825-1895), the would-be engineer who became a leading biologist and the most astute controvertialist against the dogma of his day; Brewster (1781-1868), the poet, preacher, physicist, the inventor of the Kaleidoscope, the biographer of Newton, and the writer of three hundred and fifteen papers on scientific subjects; and Tyndall (1820-1893), the Irish National-school boy who became an engineer, a student in Germany, a professor of natural philosophy at the Royal Institution, a good sportsman, a colleague of Faraday, a physicist of the first rank, who made the Alps his own, and a writer unexcelled in the whole range of scientific literature. With the exception of Brewster, none of the group received what may be called systematic education, all were ardent research workers, all became Fellows of the Royal Society, all were distinguished writers. A man is known by his friends, and by these we may know Charles Wheatstone.

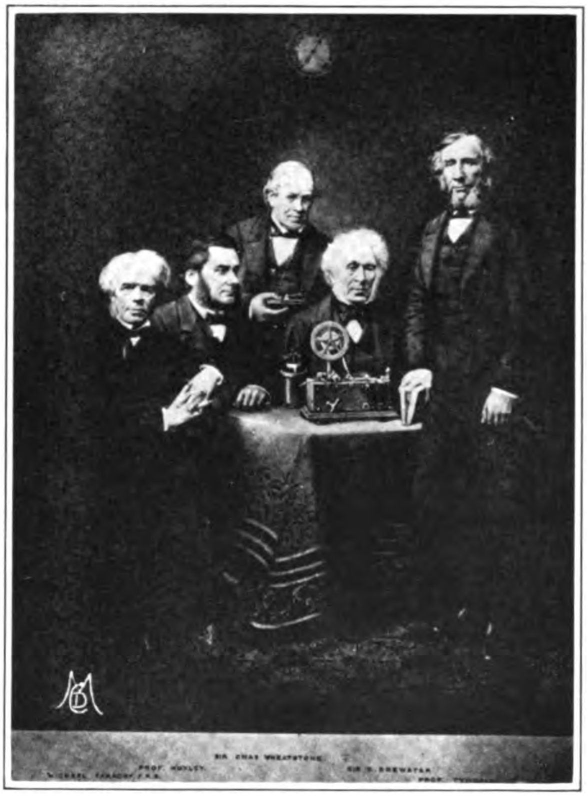


Figure 20—Michael Faraday, Professor Huxley, Sir Charles Wheatstone, Sir David Brewster and Professor Tyndall

Methods of Introducing Automatic Telephony to the Public

By A. SANDMEIER

Member of the Direction Generale des Telephones of the Swiss Government at Berne

THE precautions taken by the Swiss Government to instruct the public in Basle before conversion to automatic telephony were amply justified by the very successful cut-over of the Basle Rotary System automatic office on the night of Saturday, September 27, 1926. Among other means adopted to popularise the system was the exhibition at the Swiss Samples' Fair of a small model of a standard installation, capable of demonstrating to prospective subscribers the methods of operation and the advantages of the system. The present is an opportune time for considering, in the light of this experience, the general problem of how to dispose of prejudices that the public at large may entertain towards automatic telephone exchange systems, and how to give assurance that such systems are advantageous.

Necessity of Instructing the Public

With the advance of technical development in automatic telephony, objections and fears are rapidly and completely disappearing. It is found to be perfectly adapted to the needs of the present time when economy and efficiency are essential. Experience shows that subscribers, when the installation is completed and the cut-over successful, quickly become accustomed to the new system and convinced of its advantages. They lose altogether the habit of making use of the manual system. Individuals have their own preferences but the new system can give satisfaction to all tastes. Wherever the manual system is not operating satisfactorily, the automatic telephone is more readily, even eagerly, accepted. It is necessary in this case to recognise a psychological condition. On the one hand, subscribers are dissatisfied with a manual system which has become inadequate, on the other hand, with the new system they become accustomed to the consequences of wrong manipulation on their part. Hence, though the public are well disposed towards the novelty, it is necessary to instruct them when introducing the automatic system, in order that they may learn how to make judicious use of the apparatus. Inasmuch as defective installations and faulty traffic methods may cause an unfavorable reaction on the part of subscribers, the primary requirement when installing automatic systems is that the equipment and operations shall be perfect. Initial circumstances will exercise a lasting influence on the attitude of subscribers towards the exchange.

A system that has been inaugurated successfully is likely, from the beginning, to increase the faith of the subscribers in the new means of communication. If it works in a defective way, however, the user fails to acquire confidence in the mechanism and tends to consider it responsible for all errors, including those due to his own failings.

After a project has been carefully prepared, steps must be taken to ensure that subscribers will become familiar, from the beginning, with the new installations. They must be taught to understand the nature, the object, and the common-sense reason for the dispositions in which they are particularly concerned. There is need, therefore, for a kind of introductory course to initiate telephone users into making the manipulations and in observing the signals employed in the automatic system. The use of the dial requires collaboration with subscribers. If, for example, it is contemplated to incorporate automatic rural exchanges within a system of automatic city exchanges—in other words, to create a group of networks consisting of city exchanges and rural exchanges within a whole territory—subscribers already partly instructed will facilitate the general initiation, and it would be useful to complete their knowledge.

The public remembers the inconvenience caused through the conversion of large capacity exchanges of the local battery system to the central battery system. It should be made clear that the putting into service of automatic exchanges is still more involved, owing to the inherent technical difficulties and the ever growing demands made by subscribers upon the telephone service. It should be pointed out also

1. Please consult the most recent Subscribers Directory to ascertain correct call number of the desired subscriber.

2. Lift receiver to the ear and await dial tone. Dial tone is the signal for "exchange free."

3. Now set the exchange code letters and numbers on the dial with the finger disc.

Read or set telephone numbers from left to right; that is, first exchange code letters (S for Safran, B for Birsig), then thousands, hundreds, tens and units figures.

Example: To call the subscriber "Safran 5789."

Lift receiver to the ear, await dial tone. Insert finger in the opening in the disc marked "S." Turn disc in right direction up to the finger stop. Withdraw finger and await for the finger disc to come to rest. Insert finger in opening 5. Dial further up to the finger stop and let it go. Then set in exactly the same manner the figures 7, 8 and 9.

The course of the disc is not to be accelerated or retarded by catching hold of the dial.

When the number is finally sent, then the desired connection will be completed by the automatic exchange.

4. If ringing tone is heard in the receiver (a short buzz tone) then the subscriber is free. The called subscriber's bell rings at intervals of 10 seconds. The caller listens to control this call. If no one answers within one minute, then hang up the receiver and make the call again later.

5. If the busy signal is heard in the receiver (a buzz tone in uniform rhythm) then the called subscriber is engaged. Hang up the receiver at once. The call can be repeated a few minutes later.

6. If, on setting the number, an error has been made in dialing, or if a new connection is desired, then press the switchhook for one second in downward direction, await the dial tone signal and set the number again correctly on the dial.

7. If conversation is proceeding, the switchhook must not be moved and the finger disc must not be turned.

8. For connections with the following service points, one should select:*

1. Enquiry for numbers which are not in the directory, and for obtaining emergency calls. . . . No. 11
2. Fault position for announcing disturbances on the apparatus, on lines or in the exchange. . . . No. 12
3. Telephone Service . . . Ordering Calls. . . . . No. 14
4. Toll Service . . . for enquiries as to the cost of toll calls. . . . . No. 15
5. Supervisory Toll Exchange for complaints regarding calls. . . . . No. 19
6. Telegram Reception Service—for delivering telegrams by 'phone. . . . . No. 10

*See also beginning of Subscribers' Directory under heading "Instructions for the use of the Telephone," Section D

Figure 1—Translation of Instruction for the Use of Automatic Telephone Stations

that the new system amply meets all requirements.

Subscribers at first are disinclined to perform the slight supplementary work demanded by automatic telephony, but the curious fact emerges that the critical adapt themselves the quickest to the new circumstances.

Modern commercial experience in many directions compels the public to appreciate the fact that the advantages to be derived from new methods and devices frequently can be gained only as the result of self-training, and that the effort is worth while. To this precept automatic telephony offers no exception.

Means of Informing Subscribers

Before automatic exchanges are put into service, the Administration of Posts and Telegraphs begins propaganda in the Press, acquires the collaboration of editors and invites their representatives to visit the new installations and to attend a conference on the subject. The collaboration of the Press is very valuable. Besides accepting for publication the communications forwarded by the Administration, the editors examine and test communications they receive from subscribers and by so doing save the Administration a great deal of trouble. When re-grouping subscribers' numbers, which is effected generally a year before placing the exchanges in operation, this collaboration proves indispensable.

Communications and instructions sent directly to subscribers are of no less moment. Addressing subscribers directly is in accordance with commercial principles, but experience has shown that attention is not always paid to communications of this kind. It often happens that they are not circulated and are, therefore, not brought to the knowledge of the persons who make most use of the telephone and who consequently have occasion frequently to establish exchange connections. In consequence of this neglect, users make omissions in strange contrast to the severe requirements they place upon the telephone service.

Communications to subscribers should urge them to submit their complaints directly and at once to the competent authority, instead of publishing in newspapers complaints concerning sporadic incidents. When the telephone service is a State monopoly, subscribers find pleasure in causing public discussions calling the Press to the rescue. This is not always to be discountenanced, but the public should be taught to realise that it is not the most effective procedure, and that there is a better way of arriving at efficiency.

Figure 1 is a translation, with schematic of the subscriber's dial omitted, of an "Instruction for the Use of Automatic Telephone Stations" distributed to the Basle subscribers before the inauguration of the automatic exchange. As soon as the sets with dials are installed, subscribers are invited to make trials. Accordingly the exchange asks them to manipulate the dial and to dial certain numbers; furthermore, it is recommended that they observe the signals such as "exchange free," "dialing tone," "ringing tone," "busy tone," etc. With this in view, operators call subscribers from suitable test positions controlling different dials, send the above mentioned signals, and direct attention to the differences by which they are characterised. On these occasions the exchange can rectify wrong ideas and can give explanations where necessary.

Subscribers at first are apt to be embarrassed by the signals. Not only do they forget sometimes how the signal "exchange free" manifests itself, but they have difficulty in discriminating the ringing tone from the busy tone. If these signals are not well distinguished both as regards pitch and intensity of sound, they are easily confounded. Subscribers must learn to decide for themselves, on hearing these signals, whether they should restore their telephone immediately (busy tone) or after a short waiting time (ringing tone repeated at regular intervals being an indication that the subscriber has not answered). It is useful, therefore, to acquaint the subscriber with the busy tone at least, before the automatic system is inaugurated. For example, beginning on an agreed date, the operator may refrain from notifying the subscriber vocally when the desired line is busy and from inform-

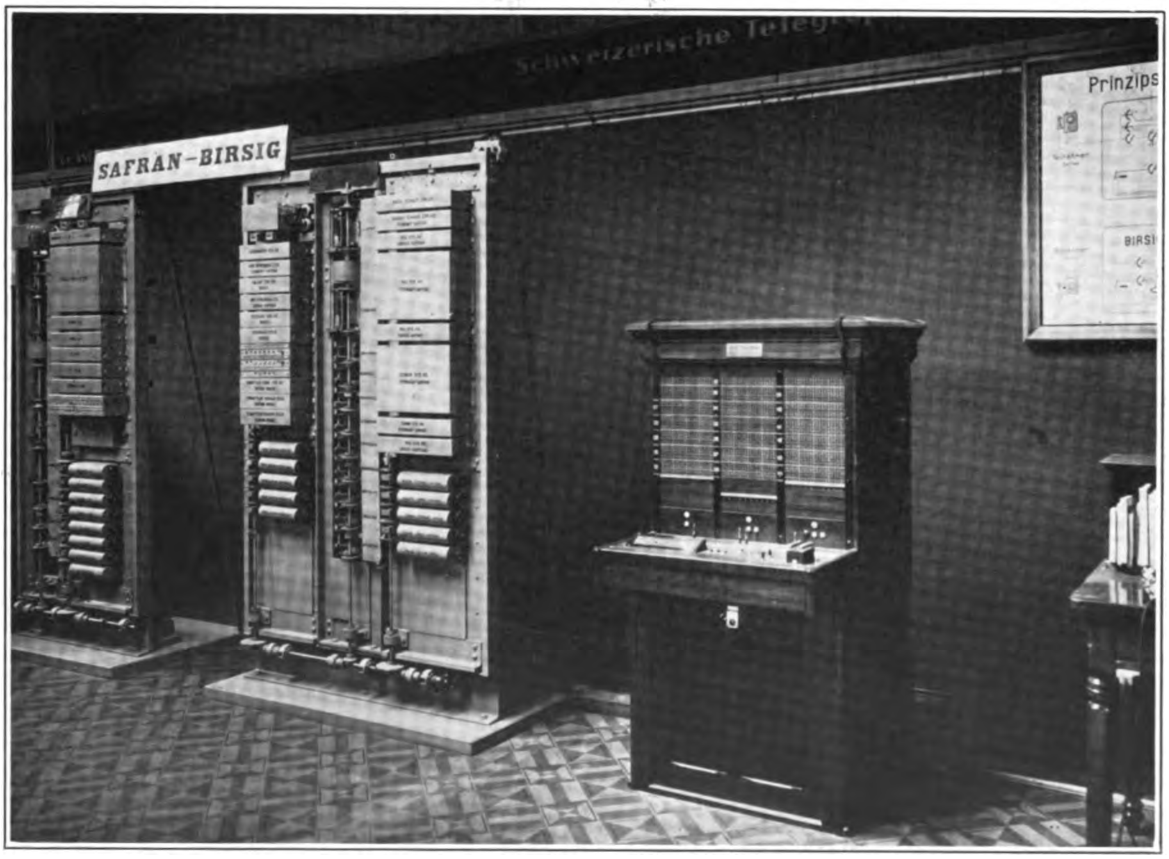


Figure 2—Model of 7-A Machine Switching Equipment, Rotary System, at Basle, and Manual Board at Birsig

ing him that he will be called again when the desired connection is free; instead, she may transmit the busy tone to the subscriber.

At Zurich arrangements have been made such that by the middle of 1927 four full automatic Rotary System exchanges supplied by the Berne Branch of the Bell Telephone Manufacturing Company, an Associated Company of the International Standard Electric Corporation, will be in operation. These are called "Hottingen," "Selnau," "Uto" and "Limmat;" the network also includes five sub-exchanges and will have a total initial capacity of 27,000 lines, which probably will be reached by 1930. Considering the severe requirements as regards quality that the Zurich subscribers place upon the telephone service, and the measures that the Administration contemplates for the inauguration of the new installation, the conversion to automatic working of the Selnau central battery exchange of 9,000 lines capacity, represents a technical problem of considerable magnitude.

Experience gained at the Samples' Fair at Basle has proved that demonstrations of automatic telephony are of great advantage. So far as Zurich is concerned it has been suggested that propaganda work be conducted at Kinemas and by broadcasting.

The apparatus for the Basle demonstration is illustrated in Figures 2 and 3. The contract stipulated that for this purpose the Bell Telephone Manufacturing Company, Berne, should deliver a demonstration model with the material for the two exchanges at Basle; i.e., "Safran" and "Birsig."

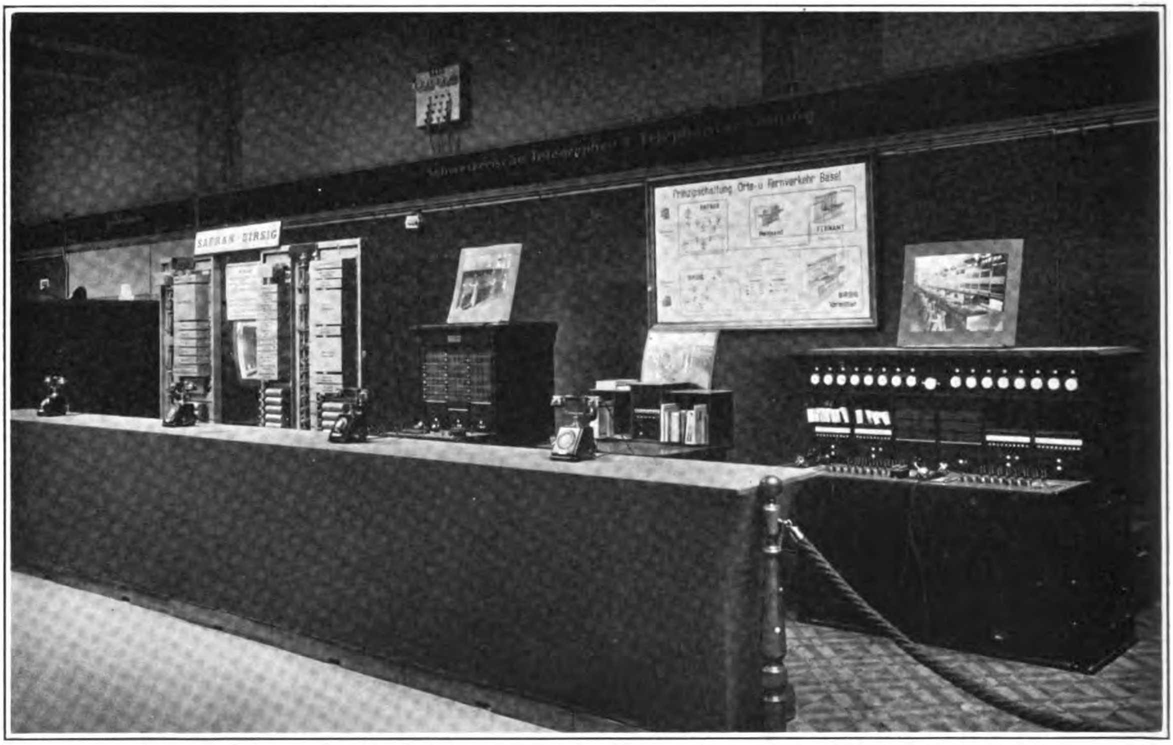


Figure 3—Model of 7-A Machine Switching Equipment at Basle, and Recording and Toll Switchboards at Safran

In order to give visitors a general idea of the actual exchanges, corresponding photographs (see Figures 2 and 3) of the apparatus under construction were placed on top of the different parts of the model. Between the bays of the apparatus bearing the inscription "Safran-Birsig" (Figure 3) was placed a view of the rows of switchracks of the Safran exchange. Above the central switchboard which represents the manual operators' positions at the Birsig exchange, a photograph showed the row of switchboards actually existing in this exchange. Above the recording position was fixed the photograph of the recording switchboards with the mechanical ticket belt carriers and pneumatic tube distributors. Finally above the right toll switchboard, one of the rows of toll switchboards of Basle was illustrated.

Before studying the fundamental diagram of the model (Figure 4), it is desirable briefly to examine the guiding motives for the installation of the new exchanges. Specialists are rather attracted to the novelties introduced in the exchanges situated beyond our frontiers; for example, the exchanges of large cities like London or Paris. The case of Basle itself presents some interest owing to the fact that the service in this city has always worked under good conditions and that the subscribers exact much from the telephone. When the required conditions are fulfilled, the introduction of new traffic methods is instructive in many respects, particularly if they cause the rental revenue of the undertaking to increase.

The traffic system which was put in practice in Basle and which comprised a single central battery office, had to be transformed completely because the maximum capacity of 9,600 lines was attained. It was necessary to install a second exchange and, consequently, to adopt the system of multi-exchanges.

The distribution of subscribers lines, already connected, or to be added, in the city area, was such that the formation of two separate cable networks was not found to be advantageous. Consequently the second exchange was accommodated in the same building as the existing exchange. It was necessary to transform the building, but the expenses have been much lower than those which would have been required for the purchase of ground and the construction of a special building on another site. By the adoption of this solution, Basle will possess two exchanges of 8,500-9,000 lines each, which will be sufficient for ten to twenty years. Furthermore, within a radius of 5 kilometers of the main exchanges, a few automatic sub-exchanges of a maximum capacity of 1,000 subscribers each are to be installed. When the decision was reached to install a second exchange in the same building as the old exchange, provision had to be made for:

1. A system of multi-exchanges with automatic operation.
2. The continuance of the manual exchange equipped with central battery which is still in perfect working condition.
3. Economical operation, keeping in mind the maintenance of the manual exchange, and the handling of calls between exchanges.

Condition 1 has been fulfilled, providing for the conversion to automatic of the Safran exchange. As regards conditions 2 and 3, they have been met, in the first instance by connecting the subscribers who make a great number of calls, to the automatic exchange and those who use the telephone less frequently to the manual exchange Birsig; then by assigning junction traffic from Birsig to Safran to the "A" operators' positions of Birsig; and lastly by installing operators' positions with visual indication of the numbers (call indicator positions) for calls from Safran to Birsig. An attempt was made to improve the efficiency, in particular of the Birsig exchange, by providing it with an automatic system for distribution of calls, which gives this exchange a semi-automatic character, although this term implies something more complete. Furthermore, the routing of the toll calls destined for the Safran exchange had to be done automatically, from the toll operators' positions, over toll final selectors. Finally, it was found necessary in the Safran and Birsig exchanges to design the circuits for the repeated metering of suburban connections. The project submitted by the Bell Telephone Manufacturing Company was realised. All the above mentioned installations were cut into service in the autumn of 1926.

The following explanations will enable the operation of the demonstration model illustrated in Figure 4 to be understood.

A connection Safran-Birsig, for example, is effected as follows:

Subscriber's set Safran, 1st line finder I A.S., 2nd line finder II A.S. (forming part of the cord circuit), register chooser R.S., register group selector G.W., and thence to calling plug and via finder S.S. and register R.O. to the call indicator lamp box of the Birsig position.

A call Birsig-Safran is routed as follows:

Subscriber's set Birsig—link circuit; i.e., line finder A.S. and cord finder S.S. to a free single plug ended cord circuit of a disengaged call distributing position. The operator to whom a call has thus been directed hears in her receiver a short tone and identifies the call by means of the flashing of the lamp corresponding to the plug. She asks the subscriber the desired number. As previously stated, the same operator has a key-set by means of which she can direct to the switching apparatus the calls destined for the automatic exchange Safran without the intervention of a second operator.

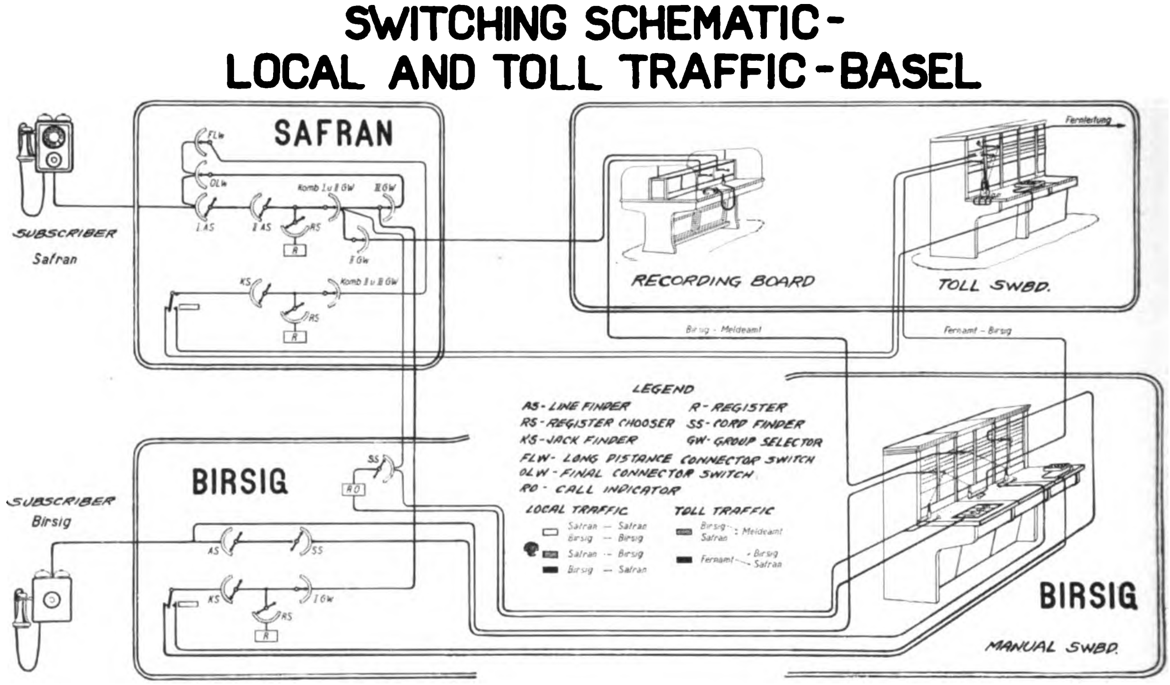


Figure 4—Diagram of Connections of Demonstration Model for Basle Area

The connection Birsig-Safran is continued as follows:

Plug, with the lamp flashing, inserted in jack, on the one side over the back contact of relay in the Birsig diagram and on the other side over the key-set and front contact of relay to jack finder K.S. of link circuit—register finder R.S., register R—then, first group selector I G.W.—third group selector III G.W. of Safran diagram—final selector O.L.W. for local calls—Safran subscriber's line, etc.

In the course of the demonstrations held with the small model during the Samples' Fair, the visitors were shown how all phases of the connections they have to establish, most frequently from thier own sets, succeed one another.

The model employs the same circuits and mechanisms as the actual exchange and its future study by the operating personnel, therefore, should prove advantageous.

Two experienced operators were charged with presenting the installation to interested visitors at the Fair. At certain times, technical employees also attended the demonstrations. There is not the slightest doubt that such an exhibition contributed powerfully towards making the Basle residents familiar with the manipulations to be effected and the instructions to be observed by automatic telephone users. Many visitors also made it a point to establish the connections themselves. In demonstrating by means of the model the different phases of the System's operation, it was possible first to give an idea of the effects of false calls—which can start alarm signals—and afterwards to show what happens when the subscriber does not wait for the dialing tone; when the caller improperly keeps moving the switchhook of the apparatus up and down, or when he dials the wrong number, etc. It has been possible also to prove the necessity for restoring the receiver promptly when the line is busy or when the subscriber does not answer. The demonstration relating to toll calls and to registering of calls was also instructive.

It was obvious that the majority of the spectators contented themselves merely with looking at the installation that was demonstrated. Others, on the contrary, followed the explanations with the greatest attention.

Service Observations Concerning the Utilisation of the New Operating System by Subscribers

Under this title, it is proposed to show how necessary it is, even after the cut-over, to continue the instruction of subscribers and to try thereby to secure a good working service with their intelligent collaboration.

To make things plain for the subscribers, the Press was resorted to and, furthermore, communications were forwarded to each subscriber; i.e., instructions in accordance with Figure 1. Subscribers from Zurich had not received such complete instructions as those from Basle. They already knew the busy tone and the ringing tone, however, for they had heard these when the semi-automatic system existed. The first column of Table I contains the percentage of false manipulations and irregularities on the part of subscribers who, after their calls were handled through a semi-automatic system, were connected to a full automatic system. The second column contains, for comparison, corresponding values relating to subscribers who have for some time been on full automatic installations. A total of 18 per cent compared with a total of 5 per cent distinctly indicates to what extent subscribers, owing to their own faults, lose the benefit of the advantages a good working telephone service offers.

TABLE I

Results of Service Observations, Subscribers of Hottingen and Limmat Exchanges, Zurich

	Percentage of faults in relation to the total number of observed connections		
False manipulations and irregularities on the part of subscribers whose calls are attended to by a full automatic exchange	1. Subscribers connected only a short time to an automatic exchange (900 connections observed) %		2. Subscribers connected for a relatively long time to an automatic exchange (12,000 connections observed) %
1. The subscriber does not observe the dialing tone and moves the switchhook up and down.	0.22		....
2. The subscriber dials, but forgets to complete a call, restoring the receiver afterwards.	0.22		....
3. The subscriber hears the dialing tone, but does not dial the number; he restores his receiver after a moment.	6.89		3.13
4. The subscriber dials his number before hearing the dialing tone.	1.45		0.18
5. The subscriber forgets to dial "Zero" at the beginning of the number; e.g., S. 715 instead of S. 0715.	0.22	7.33	1.32
6. The subscriber does not dial code letter of the exchange.	0.44		
7. The subscriber only dials 4 digits, in this case it has not been possible to verify whether it is the "Zero" which has been omitted or the code letter of the exchange.	4.78		
8. The subscriber only dials 3 digits.	1.11		
9. The subscriber only dials 2 digits.	0.78		
10. The subscriber dials a total of 6 digits.	1.00		....
11. The subscriber has dialed 9 digits.	0.11		....
12. In dialing, the subscriber confounds the tenths with the units; e.g., 71 instead of 17.	0.44		....
13. The subscriber dials false code letters.	0.33		....
Total of wrong calls and false connections for which the subscriber is incontestably responsible.	about 18%		about 5%

In Table I will be found the results obtained while observing the subscribers of the Zurich exchanges, Hottingen and Limmat. Important groups of subscribers, who formerly were connected to the semi-automatic exchange of Hottingen, were connected partly to the automatic exchange Hottingen and partly to the Limmat exchange.

Even in the case of an exchange designed and tested carefully for a given capacity, a certain degree of confusion is always brought about in the busiest hours (peak load) at the beginning of its operation. The fault lies undeniably with the subscribers as shown in Table I. The data of column 1 refer to a period of zero to eight days after the cut-over. They thus correspond approximately to the peak of the fault curve which, after about two months, reaches the value of column 2. The high figure of faults expressed in percentage in column 1, proves clearly that during the first hours and the first days that follow the introduction of the system, all the positions in the exchange where the observation of the traffic can be made, should have enough personnel to help the subscribers.

When the new exchanges have been in operation for some time and it has been ascertained through the service observation that conditions have again become normal, it is necessary to pay great attention to the opinion of subscribers regarding the telephone service. During the inauguration of the new exchange and the critical period following it, the opinion of the subscribers about the telephone service may be unfavourable. The improvement that the new system brings, as a rule, is criticised and even contested in spite of the fact that the service of the exchange may be considered satisfactory. Once the subscribers get accustomed to the new installation with consequent improvement in the service rendered, this opinion manifested by criticism and occasional complaints is at variance more and more with the actual facts.

It is precisely this time that is chosen by the Swiss Telephone offices to consult the subscribers by means of circulars. The front of the circular letter is reserved for the request and the back for the answer. The subscribers are asked whether they are content with the telephone service and whether the service has given them satisfaction lately. Thus they are compelled to discriminate between the past and present—which is of moment.

It can be concluded from the subsequent attitude of the subscribers that the advantage of such consultations is great. They are favourably influenced because these consultations convey the impression that the administrative body is interested in their opinions.

Table II contains a summary of subscribers' replies.

TABLE II

Summary of Subscribers' Opinions of the Telephone Service

Consultation of 100 Subscribers of the Sub-exchange "Hongg"—Full Automatic System

80 are satisfied, 13 among these still have criticisms of a slight nature to bring forward. The subscribers readily avail themselves of the opportunity offered to present minor observations, etc.
12 are satisfied after the telephone service has been in operation a short time. Observations, none.
8 are dissatisfied altogether; all have criticisms to make.

Consultation of 100 Subscribers of the Sub-exchange "Oerlikon"—Full Automatic System

60 are satisfied; observations, none.
25 have been satisfied for some time.
15 are dissatisfied; all have criticisms to make.

Consultation of 100 subscribers of the Sub-exchange "Tiefenbrunnen"—Full Automatic System

71 are satisfied. Among these 12 have criticisms of a minor nature to bring forward.
21 have been satisfied for some time; one of them presented an observation.
8 are dissatisfied; all have criticisms to make.

Consultation of 100 subscribers of the Sub-exchange "Hottingen"—Full Automatic System

86 are satisfied. Among these 12 have criticisms of a minor nature to bring forward.
12 have been satisfied for some time. Among these 3 presented observations.
2 are dissatisfied; all have criticisms to make.

Remark: The cases of criticisms were dealt with later in writing.

Another means likely to correct wrong opinions is to invite the subscribers to visit the exchanges, so that they may place absolute trust in the installations. Thus, the Hottingen exchange, in the course of ten years, has been visited by about 4,000 persons, mostly in societies. The explanations given on those occasions by qualified employees have brought good results.

Finally, there is a certain class of scattered subscribers, to whom the exchange personnel must pay special attention. These persons are refractory and on account of their complaints and their unreasonable pretentions often cause the technical staff to lose their patience. At times, the cause of complaint is the message registering; they doubt the accuracy of the recording of the automatic message registers. It is true that errors in message registering are not altogether excluded, but as the number is small and often in favour of the subscriber, the

Swiss offices have every reason to acknowledge general accuracy. By special statistics, the proportion of errors has been established. Table III gives the results obtained in the Geneva Rotary exchange "Mont Blanc" during the months of January to May, 1926.

TABLE III

Message Registering Errors—"Mont-Blanc" Rotary Exchange

1926	Number of tests	Calls to exchange service; the message register should not operate	Calls to subscriber of: " Mont-Blanc " the register should operate	"Stand" the register should operate	Errors Total	%
January	2,961	..	1	6	7	0.24
February	2,990	2	..	5	7	0.23
March	3,002	3	..	1	4	0.13
April	3,223	..	1	4	5	0.15
May	2,964	..	1	8	9	0.30
Total	15,140	5	3	24	32	0.21

Table III shows that, according to exact reports, the percentage of registering errors for Mont Blanc has only been 0.21 per cent. It should be noticed that, as a rule, the subscribers readily pay the monthly taxes of the calls made through the Swiss offices. In certain cases where, for any reason whatever, the monthly indications of the registers were not exact (the message registers recording mostly too few calls and rarely too many) it has been easy to avoid losses, even for the Administration, after an understanding with the subscribers.

Nevertheless, in certain rare cases, it happens that subscribers continue making complaints, notwithstanding the fact that their complete installation, including the message register, has been tested with the utmost care and found perfect in operation. Such subscribers generally make a habit of recording their calls.

In this instance and also in the case where subscribers persistently complain of bad telephone service in general, the Administration have connected the subscribers' line to observation positions without informing them of this action. Although the organisation of the service observations fulfills the right purpose, nevertheless, these observations must be made with the utmost care in order that when it comes to definite discussion with the subscribers on the basis of irrefutable proof, the desired effect can be obtained. The observations should be of such accuracy that the complainers are completely disarmed.

In order to have a record reflecting faithfully the traffic passing over the observed subscribers' lines, a relatively large amount of work is being done. The effort is likely to be doubly profitable, first, because the controlled subscribers will hesitate in future to renew their criticisms and, secondly, because the public is thus informed of the effective means of control the Administration possesses. Fortunately, unwarranted cases of complaint are not numerous; the exchange Mont Blanc regained its calmness after a dozen of such observations. In cases of this kind, it is not only necessary to make the usual observation of the different phases of a call, but it is desirable to record exactly the hour when the call is established. Likewise, particulars of the conversation must be noted, such as the presumed name of the correspondent, etc.

On the basis of the results obtained through the observations made—of which the number is generally 100—a trustworthy official deliberates with the controlled complainers. This kind of deliberation provides surprises of different kinds.

Example I—The subscriber contends that his monthly account comprises 10 to 15 local calls too many.

Result—The service observations made involve a total of 50 conversations; the number of paying conversations correspond to the indications of the registers.

The subscriber himself had only recorded 46 during the same period, but after having examined the documents presented, he testified to having forgotten 4.

Example II—The subscriber complains that too many calls have been recorded on the account and that he has been wrongly connected several times.

Result—The office observes 115 calls which are distributed as follows:

Calls when the line was busy	4
Unanswered calls	2
Connections established, one of which wrongly	35
Calls to special services	7
Incoming calls	67
	115

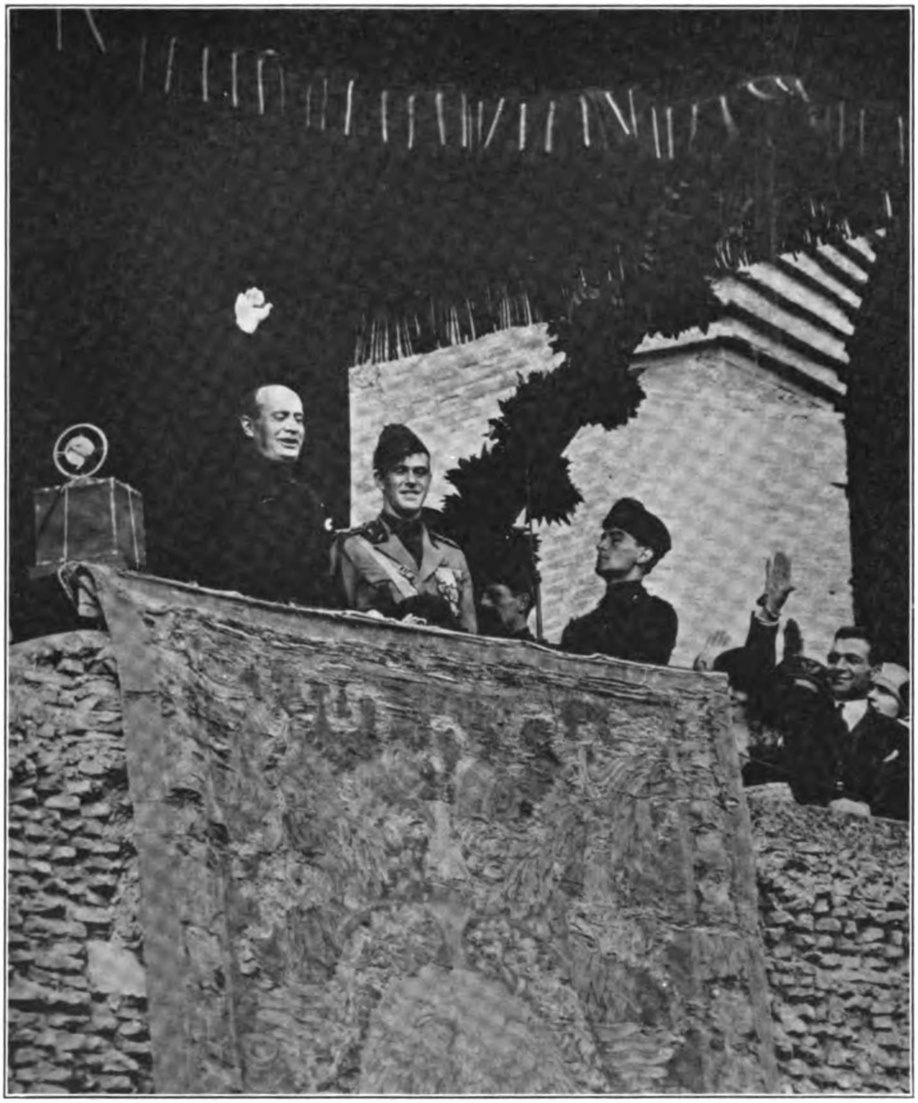
The message register had operated altogether correctly. The single false connection might have been due either to the switch mechanism or to the subscriber.

Example III — The subscriber complains strongly that he has been taxed too much, wrongly connected, etc.

Result—The office observes 273 calls of which the details are as follows:

The subscriber takes off the receiver and hangs up without having dialed the number	7
Same case, save that the subscriber dialed the number, but not completely	9
Calls when the line was busy	12
Unanswered calls	16
Connections established of which 4 wrongly	167
Calls to special services	62
	273

The indications of the message register were exact. The four false connections might be attributed either to the switch mechanism or to the careless work of the subscriber. The observations made enabled the office, nevertheless, to establish irrefutably that the calls of the subscriber were correctly handled and that his own mistakes had caused inconvenience both to himself and to the Administration.



Signor Mussolini Making a Speech at the Coliseum in Rome on the Occasion of the Fourth Anniversary of the Fascisti March on Rome. The microphone and amplifier employed in connection with the broadcasting of the program are shown at the left. They were furnished by Standard Elettrica Italiana

The Kone Loud Speaker

By S. HILL

Engineering Department, Standard Telephones and Cables, Ltd.

THE faithful reproduction of broadcast speech and music is a problem which requires for its solution painstaking study of the complete broadcasting system from the microphone in the carefully arranged studio to the loud speaker and its environment. The real measure of success can only be ascertained by direct comparison of the sounds originating before the microphone with those reproduced by the receiver. If these two performances are not noticeably different, then the problem can be said to have been satisfactorily solved.

A fundamental requirement in loud speaker design is that alternating currents corresponding to the frequencies encountered in musical sounds must be reproduced with uniform efficiency. In modern musical instruments, the frequency may vary from 30 to 10,000 cycles a second. Speech frequencies fall well within these limits.

Loud speaking receivers may be considered as consisting of two parts: a suitable mechanism, generally an electromagnetic device, for converting electrical impulses into mechanical movements, and a coupling device, whereby the motion of the mechanism is transferred to the surrounding air.

The mechanism used in the Kone loud speaking receivers is of the balanced armature type in which the armature with its attached diaphragm is not subjected to a magnetic pull unless a current is flowing through the coils. This has the great advantage that asymmetrical distortion due to unequal reproduction either of positive or negative portions of the energizing current is avoided. The stalloy pole pieces (a.a.), illustrated in Figure 1, are polarised by a large permanent magnet (not shown). The efficiency of the magnet system is increased by supporting the armature (b) centrally by means of spring lugs and suspending it symmetrically in the air gap. The coils (c.c.) occupy the cavity in the pole pieces and surround but do not touch the armature.

When current of speech frequency is passed through the coils, alternating poles are formed on the armature which is thus set into rotary vibration by interaction with the permanent magnetic field. The vibration is communicated to the diaphragm by means of the connecting rod (d), lever (e) and push rod (f). The whole mechanism is mounted on a rigid spider, screwed to the main frame.

In general, there are two types of mechanical-acoustic coupling devices, the small diaphragm with a horn and the large diaphragm without a horn. The function of the horn is analogous to that of a transformer inasmuch as it is capable of coupling two unequal impedances in a manner such that the maximum possible energy transfer is secured. Owing to the limitations of physical materials, the small diaphragm is normally of high impedance in comparison with its radiation resistance in free air. It is, therefore, necessary to load it with the higher acoustic impedance represented by the narrow end of an exponential horn of slow taper. As a coupling device a horn is highly efficient, and modern methods of design enable it to be built so as to reproduce satisfactorily any desired frequency range. The theory of the horn, however, shows it to act as a high-pass filter; that is, there is for each horn a fairly definite cut-off frequency and below this frequency the horn ceases to operate satisfactorily. In order to provide for low

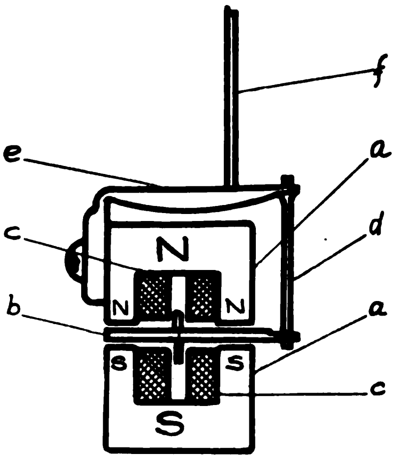
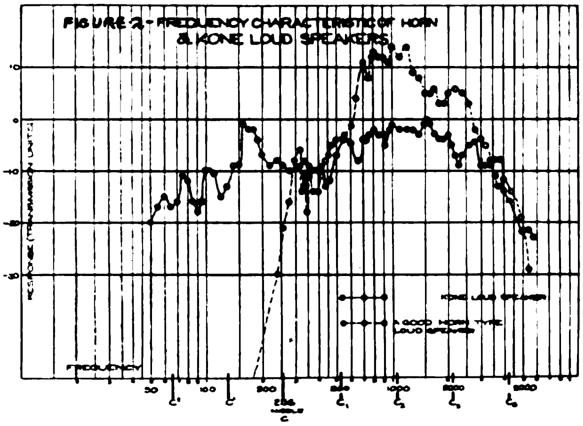


Figure 1—Balanced Armature Mechanism

frequencies, a low rate of taper and a considerable mouth opening are required so that horns capable of covering a satisfactory frequency range tend to become large and costly. The size fitted to the usual horn loud speaker is quite inadequate to handle the lower frequencies. In many cases, the quality of such receivers is harsh and unnatural due to poor reproduction of frequencies a little below middle "C" (250 cycles per second). It is for this reason that the large diaphragm type of receiver has been developed.



The large diaphragm type of coupling device introduces its own difficulties. Instead of a light sheet of air at the mouth of the horn, there is a material diaphragm possessing mass and elasticity. Owing to fall in radiation resistance, the efficiency at low frequencies decreases as the diameter of the diaphragm is made smaller.

The Kone type of loud speaker produced by Standard Telephones and Cables, Ltd., is an outstanding example of the large diaphragm instrument. The diaphragm consists of paper cones cemented around the bases which are approximately 18 inches in diameter. The apex of the cone is made to hold the push rod (f) of the magnet system (Figure 1). The rear cone is cut to a frustrum, the smaller circular portion being clamped to the frame. The back is closed in by means of a dust-proof screen. The frame, which is of suitably finished metal, is provided with a handle at the upper end. The appearance of the speaker is illustrated in Figure 6.

The material, shape and dimensions of the one diaphragm have been chosen to secure a compromise between weight and rigidity, the problem being somewhat complicated by the need for a material capable of meeting all ordinary atmospheric conditions. The paper used is particularly good in this respect; it is a handmade bookbinding paper of close and uniform texture.

The constants of the diaphragm have been matched by trial in such a manner that the various modes of vibration of which the diaphragm is capable, blend to give a substantially uniform response over a wide range of frequencies, as indicated by the characteristic curve (Figure 2). These modes of vibration can be observed in the well-known manner by placing the diaphragm of the receiver in a horizontal position and sprinkling it with sand while a steady alternating electromotive force is supplied to the instrument from a suitable oscillator. It is found, in the case of the instrument discussed, that there are four distinct types of vibration: viz., (1) a rocking vibration about a diameter, (2) a sector vibration, (3) an annular vibration and (4) a transition between the last two forms. The first type of vibration (Figure 3) occurs at frequencies up to 100 cycles per second. Towards the lower end of this range there may be a fifth type of vibration in which the diaphragm moves as a whole. In the second mode of vibration, illustrated by Figures 4 and 5, the surface of the Kone moves in sectors varying in

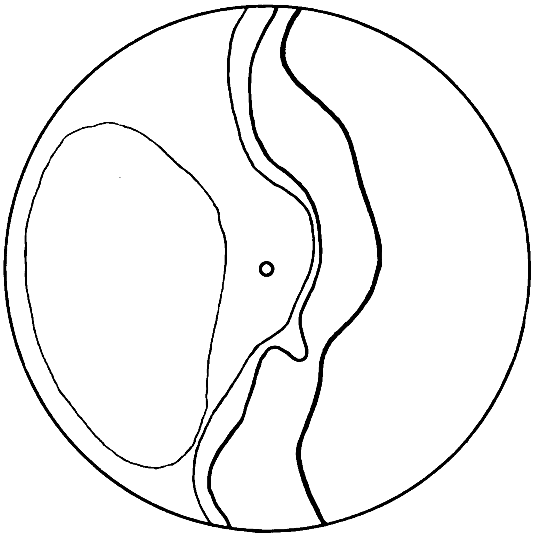


Figure 3—Sand Figure Obtained When the Kone Rocks about a Diameter

number from about 4 at 110 cycles per second, to 16 in the neighborhood of 150 cycles per second. Above about 800 cycles the Kone vibrates annularly, the sand being thrown into concentric rings. Between 150 and 800 cycles per second the transition stage occurs in which the sectors break up into small patches, arranged concentrically and decreasing in size as the frequency is increased. The blending of these various modes of vibration produces a large number of small resonances as shown in the response curve (Figure 2). These resonances, being both small and numerous, give results substantially the same as would be obtained from a smooth curve.

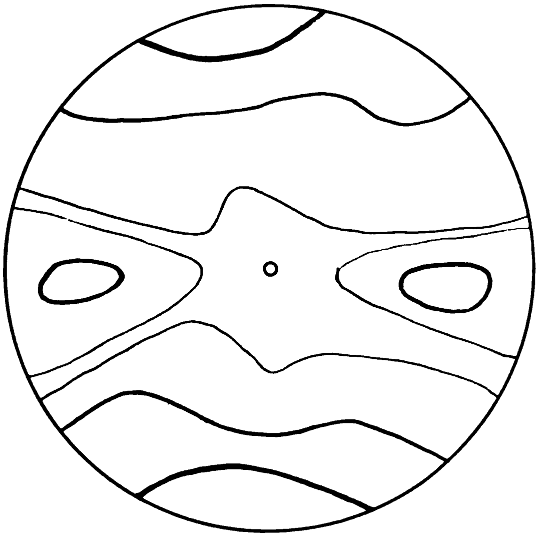


Figure 4—Sand Figure Given by Sector Vibration of the Kone at a Frequency of about 110 Cycles per Second

In order that the advantages indicated by the wide scope of the response curve may be fully obtained, the Kone must be operated under the proper conditions. This is especially important, since, as is well known, a loud speaker reproducing over a wide frequency range is more sensitive to overloading in its associated amplifier than is a loud speaker reproducing within a narrower range. It is evident also that unless the amplifier is capable of reproducing over a range at least as wide as that of the loud speaker, the advantages of the wider frequency range of the loud speaker may be completely lost. It frequently happens, for example, that the Kone is used with an inferior receiving set or amplifier which either distorts or does not reproduce some important part of the frequency range. In such cases the Kone cannot be expected to replace the missing frequencies or to correct the distortion. When used with a faulty set, the Kone may indeed sound worse than a greatly inferior instrument, because it can bring out defects in the set, such as distortion due to absence of grid bias or to overloading of the valves, which a poorer speaker might largely mask. There is no difficulty, however, in constructing a set, in accordance with known principles, capable of giving the high-grade performance necessary for obtaining the superior quality of reproduction which characterises the Kone Loud Speaker.

For home use a good receiving set and an amplifier terminating in valves of adequate power capacity as well as proper matching of the output of the loud speaking amplifier to the impedance of the Kone are well worth while.

If an amplifier be provided with an output transformer of variable ratio, so that its output impedance can be varied, and if a steady tone be applied to such an amplifier and reproduced by a loud speaker, it will be found that maximum volume is obtained when the impedance of the amplifier is equal to that of the loud speaker. If the experiment be performed at different frequencies, the same setting probably will not

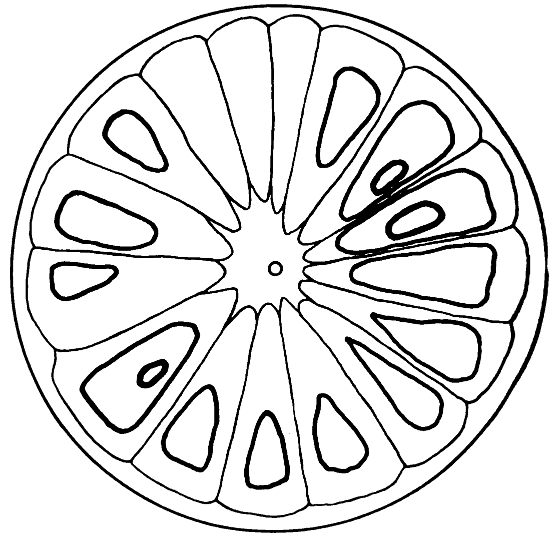


Figure 5—Sand Figure Given by Sector Vibration of the Kone at a Frequency of about 150 Cycles per Second

give loudest results in all cases, because the impedance of the loud speaker at each frequency is not necessarily the same. Hence, a setting that gives exact impedance matching for one frequency does not necessarily do so for another. Under actual working conditions where the impedances are not capable of adjustment, there will always be one frequency which is reproduced better than the others because the impedance of the set and loud speaker match at this frequency. The choice of the impedance of the set or amplifier is important, because it controls the matching frequency and so influences the character of the performance. If the impedance of the amplifier is too high, matching will occur at high frequencies and may result in overaccentuation of the higher range. Similarly, if the impedance is too low, the lower frequencies are accentuated.

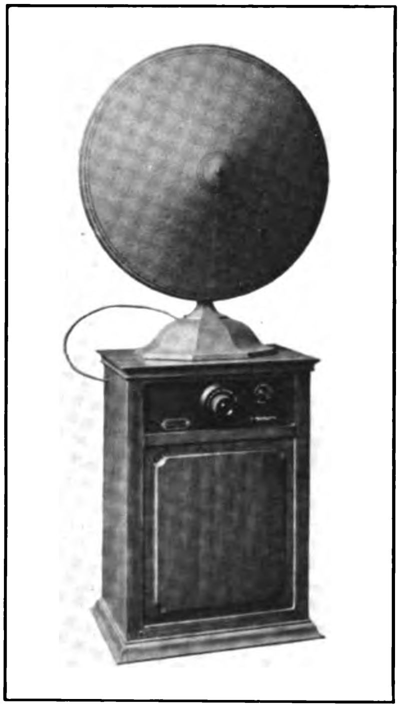


Figure 6—Kone Loud Speaker with Associated Kone Amplifier

The design of the Kone produced by Standard Telephones and Cables, Ltd., is such that the best results are obtained from an amplifier of about 2,000 ohms impedance which gives impedance matching at about 300 cycles per second. The Kone, however, may be connected directly in the plate circuit of any good power valve without excessive unbalance of the tone scale, provided that the valve impedance does not exceed 10,000 ohms. Where it is used with valves of lower power handling capacity (which are generally of high impedance), a suitable transformer should be used to reduce the output impedance of the amplifier to 2,000 ohms.

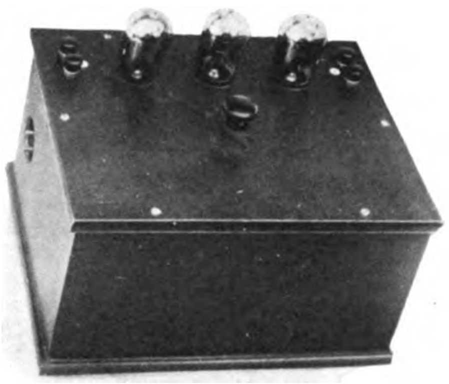


Figure 7—Amplifier Operating from D.C. Mains

An amplifier known as the Kone Amplifier has been specially designed by Standard Telephones and Cables, Ltd., for use with the Kone speaker (Figure 6). In addition to the valves, it contains two transformer coupled stages, and also an output transformer which gives the correct output impedance of 2,000 ohms. The three transformers have been especially matched to produce substantially uniform amplification of all frequencies within the musical range.

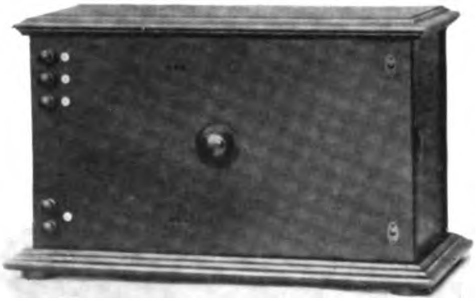


Figure 8—Amplifier Operating from A.C. Mains

As made by the Bell Telephone Manufacturing Company, Antwerp, the impedance of the

Kone Loud Speaker is twice that of the above mentioned loud speaker, and the corresponding amplifier impedance is doubled; hence, the preceding general remarks apply in terms of twice the impedances concerned.

A special associated two-stage amplifier is made by the Bell Telephone Manufacturing Company, which contains two valves in push-pull in the last stage, each of the same power handling capacity as those used in the previously mentioned amplifier. The amplification of this special apparatus corresponds to just over 50 transmission units, or to 10^5 on a power basis; its response characteristic for practical purposes may be considered flat between 50 and 5,000 periods per second. This amplifier is made in three forms which differ only in the nature of the power supply arrangements. One type is designed to operate from batteries, a second type is designed to operate completely from 110 volt D.C. mains, while a third type employing valves for rectifying purposes is designed to operate entirely from A.C. mains, taps being provided to adapt it to voltages of 110, 125, 150 and 220. Filters are provided to eliminate noise from the power mains. The second and third types are shown in Figures 7 and 8, respectively.

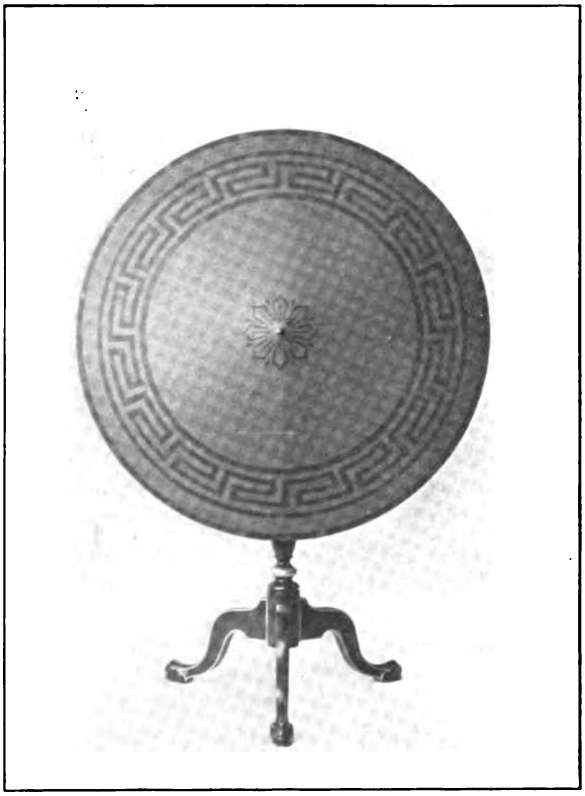


Figure 9—Large Kone Loud Speaker

The conditions under which a loud speaker is heard have an important bearing on the quality of reproduction. If, for instance, a person is speaking in a quiet conversational tone and the volume delivered by the loud speaker is made too great, the result will sound unnatural; whereas, if he is speaking as if addressing a considerable audience, natural reproduction can best be secured by increasing the volume and listening as far away from the receiver as possible. Reverberation, or reflection in the room, also plays an important part in reproduction. If possible, therefore, experiments should be made to determine the most suitable position for the loud speaker.

It is evident that no loud speaker should be expected to remedy the shortcomings of the receiving apparatus and amplifiers which precede it; and, in order that the best results may be obtained from the Kone Loud Speaker, it is necessary that ordinary precautions be observed in the design of such apparatus. With a simple resistance coupled amplifier terminating in almost any well-known make of power valve, the Kone Loud Speaker is capable of reproducing the rich tones of an organ or a pianoforte accompaniment with surprising fidelity. Sibilant speech sounds are also well reproduced.

In addition to the 18 inch speaker, a Kone type (Figure 9) employing a diaphragm 36 inches in diameter and the same magnet system as the smaller instrument has been developed. It is intended for use with a radio receiving set but under certain conditions can be employed with a Public Address System. It reproduces the lower notes of the cello, organ and piano and the brass instruments even more faithfully than the 18 inch Kone.

European Telephony as Affected by the International Telephone Committee—"C. C. I."

AMONG the very interesting phenomena, which occurred in Europe in the years immediately following the War, was a crop of so-called "international" organisations. The scope of these numerous bodies covers a wide field of activity in commerce and industry, as represented by railways, tramways, electric traction of all kinds, sleeping cars, production and distribution of electricity, telephony, telegraphy, broadcasting, etc. To trace the causes of this movement towards internationalism (which, *faute de mieux*, means "Europeanism") would be an interesting study for psychological historians. There appears to be no doubt, however, that if not directly caused, it certainly received a powerful stimulus and impetus from the propagation of the idea underlying the creation of the League of Nations. In view of the importance which one of these organisations, known as the "Comité Consultatif International des Communications Téléphoniques à Grande Distance" (generally abbreviated to "C.C.I.") has assumed in the development of telephony in Europe, readers of this journal will doubtless be interested to have some information with regard to its composition, its aims and its achievements.

In order to obtain a clear idea as to what this body is and does, it is desirable to examine briefly its history. The movement towards internationalism in this particular case was undoubtedly strengthened by the striking advances in the field of long-distance telephony, which had taken place immediately before and during the War. The development and application of the 3-electrode vacuum tube in the telephone art gave the telephone engineer a tool which enabled him to accomplish astonishing achievements and to annihilate distance as an obstacle to telephone communication.

As an example of what was done, it is well known that all the main armies were using telephone repeaters on both underground and open wire lines. Immediately upon the conclusion of peace several European countries, notably Germany, Great Britain, Holland and Sweden commenced actively the installing of new long-distance cables in their respective territories. Other countries, for example, France, Italy and Switzerland, began the planning of national long-distance cable networks.

The main technical problems of long-distance telephony had already been practically solved; any reasonable doubt on this score had been effectively removed by the fact that, as early as 1915, commercial telephone service was given in the United States between Boston and San Francisco, a distance of 5,840 kilometers. What was needed in Europe after the War was some impetus to bring together the various telephone administrations and, in some way, so to coordinate their efforts in the utilization of existing telephone plant and in the design of new equipment as to make European long-distance telephone communication a commercial success.

In 1922 a new phase was commenced. Mr. Frank Gill, European Chief Engineer of the International Standard Electric Corporation in his Presidential Address to the Institution of Electrical Engineers (British) delivered on November 2, 1922, called attention to the urgent necessity of treating international telephony on a unified basis; and of three definite proposals then made, one was that the operating telephone authorities should form an association for this and other matters and that an early international conference should be held to initiate the project.

On March 12, 1923, an international meeting took place in Paris, at the invitation of the French Government, expressly to consider these proposals and the existing C.C.I. is the direct and immediate descendant of that meeting.

At this conference the following countries were represented: Belgium, France, Great Britain, Italy, Spain and Switzerland. The conference met in the form of a "Preliminary Telephone Committee for Long-Distance Telephony in Europe," and resolved, as a result of the deliberations, to form a permanent body, to be known as the "Comité Consultatif International des Communications Téléphoniques à Grande Distance" with the task of "preparing completely the organisation of international telephony in Europe." As a first step towards this end, the Committee resolved to attempt to unify the views and practices of the various telephone administrations of Europe and to centralise technical and statistical information.

It was clearly laid down that resolutions which might be taken by the C.C.I. would be in the nature of general recommendations, to which the various countries of Europe should be invited to conform as strictly as possible in their own as well as in the common interest. It was also decided that the Committee should meet generally once a year. A Permanent Sub-Commission was formed to maintain continuity between conferences. This Sub-Commission was composed, in the first instance, of a representative from each of the following countries: Belgium, France, Great Britain, Italy, Spain and Switzerland, each delegate having one vote in the deliberations.

The first conference of the C.C.I. proper, took place in April, 1924, and was convened as a result of the preliminary meeting in the previous year. At this conference, the following countries were represented: Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Holland, Hungary, Italy, Latvia, Luxembourg, Norway, Poland, Sweden, Switzerland, Czecho-Slovakia and Yugo-Slavia. Representatives of the telephone industry were also invited to collaborate and advise in the deliberations as assessors to their respective administrations, but with no voting power. The conference confirmed the resolution referred to above, passed by the preliminary conference, affirming the main object of the C.C.I. The following additional countries, it was decided, should be added to the Permanent Commission: Austria, Germany, Holland, Czecho-Slovakia and Yugo-Slavia. The task of the Permanent Commission was to prepare and facilitate the work of the C.C.I. and the practical and detailed application of the decisions taken by the Committee, and to indicate the methods of execution.

The administrations belonging to the C.C.I. were invited to communicate to the Permanent Commission all the proposals for new international lines, together with essential technical details. Where these proposals deviated in any way from the general recommendations formulated, the whole of the details of the proposals were to be submitted to the Permanent Commission in order that the latter might be able to study any modifications that might be made to existing rules.

The second conference of the C.C.I. was held in Paris in June, 1925, and the third and latest conference in the same place in November, 1926. The number of countries participating have now increased approximately to twenty-five, the additions being Lithuania, Portugal, together with her Colony, Mozambique, Rumania and the Union of Sovietic and Socialistic Republics (generally abbreviated "U.S.S.R.").

The admission of Mozambique and U.S.S.R. was due to an interesting development which took place between the second and third conferences of the C.C.I. The Communications and Transit Organisation of the League of Nations had had its interest aroused by the importance of the role which the C.C.I. was filling and was evidently destined to fulfill in the domain of European communications, and had suggested the affiliation of the C.C.I. with the League of Nations, in accordance with the terms of the Peace Treaty of Versailles, which provided that any organisations of an international character founded subsequent to the Treaty would automatically form part of the League of Nations. Unfortunately, Germany was not then a member of the League of Nations, and she naturally felt that the important position which, by virtue of her technical achievements and experience in long-distance telephony, she had acquired in the counsels of the C.C.I. would be undermined if that body were taken over by the League of Nations, in which she had no place. A way out of the difficulty appeared to be the incorporation of the C.C.I. in the International Telegraph Union, of which the first conference after the War took place in September, 1925. This solution found support in various countries in the centre, east and north of Europe, and was ultimately adopted by a resolution passed at the conference of the International Telegraph Union. By this resolution the C.C.I. was incorporated in the Union. The resolution forms the present charter of the C.C.I. It does not go quite so far as to assert that the C.C.I. "should be entrusted with the complete preparation of the organisation of telephony in Europe," but states merely that the C.C.I. shall be entrusted with the study of standard arrangements regulating technical and exploitation questions concerned with long-distance telephony. The C.C.I., it lays down, shall centralise all information which is necessary for the study of long-distance telephony, and pass resolutions on the subject. Otherwise the International Telegraph Union leaves the C.C.I. free to establish its own organisation and methods of work with the proviso that the Union be kept informed of all the resolutions passed, which, in future, have to be published in its official organ—the "Journal Télégraphique." Two facts of importance resulted from this action on the part of the Telegraph Union. The first was that the League of Nations can no longer claim the incorporation of the C.C.I. in the League organisation; secondly, any government administration of any country belonging to the Union, which embraces the whole world, as distinct from Europe only, can now become a member of the C.C.I. on application. By virtue of this latter fact it was that the Union of Sovietic and Socialistic Republics and Mozambique were admitted to membership of the C.C.I. at the third conference.

At the November, 1926, conference, the internal organisation of the C.C.I. was modified. The Permanent Commission was abolished. This Commission had been found to be somewhat unwieldy and had not in point of fact been able to carry out satisfactorily, owing to its size, the functions for which it was originally intended. The following is a resumé of the new organisation of the C.C.I.: In place of the Permanent Commission it was decided to constitute "Commissions de Rapporteurs." These Commissions have to be appointed by the full conference of the C.C.I., to be held once a year. Their number and constitution depends upon the number and nature of the questions to be studied. Each Commission appoints a Rapporteur Principal, responsible for directing the work of the Commission. The rapporteurs make a detailed study of the questions submitted to them for investigation, and each group endeavours to arrive at common agreement and to prepare, if possible, a unanimous report on their conclusions. If necessary, the rapporteurs meet at some agreed place and confer amongst themselves or with the collaboration of representatives of the private electrical industry. The agreed reports, together with the supporting documents, have to be forwarded to the General Secretary of the C.C.I. in Paris, at least a month before the date of the full conference, so that the reports may be circulated to delegates, who will be present at the full conference, and so that these delegates may have time to peruse and consider the reports before the conference meets. The reports are discussed at the full conference and voted on by delegates. The minutes show in each case whether the reports have been adopted unanimously or by majority only. The General Secretary, whose office is in Paris (23, Avenue de Messine) is elected for an indefinite period, but the President of the C.C.I. is elected annually at the full conference (Assemblée Plénière).

Let us now try to disengage from the foregoing somewhat sketchy summary of the history of the C.C.I., a clear idea of what this body is, and the purpose for which it has been constituted.

The C.C.I. is a branch of the International Telegraph Union. It is allowed to arrange its own internal organisation and has a separate budget, to which members appointed by twenty-five government administrations, comprising practically the whole of the countries of Europe, contribute on a basis fixed from time to time by itself. It holds a conference at a centre agreed upon, once a year. At these conferences are discussed the reports, affecting the development of telephony in Europe, which have previously been studied by selected delegates (known as "Rapporteurs") nominated by certain government administrations, who themselves have been elected for this purpose at the preceding conference.

The President of the C.C.I. is elected annually; he is assisted by a General Secretary and Secretariat with headquarters in Paris. The General Secretary centralises and distributes information obtained from all sources to the rapporteurs, whose "rapports" he receives and circulates before conferences to all members of the C.C.I. He also communicates with other international bodies in connection with any queries, requests for information, etc., which these bodies, as well as administrations, may address to the C.C.I. from time to time. The questions, studied and discussed by rapporteurs and by all members at annual conferences, relate to the investigation of the developments and improvements affecting telephony in both its technical and its operative aspects. When new inventions and methods suitable for international adoption come to light, the C.C.I. studies these in detail and endeavours to specify the best methods by which they can be applied, in a standardised form, in practice. The conclusions arrived at as the result of conferences, to which experts from the private industry, as well as representatives from other international bodies, such as the Advisory and Technical Commission of Communications and Transit of the League of Nations, the International Union of Railways, the International Chamber of Commerce, the International Electro-technical Commission, the International Union of Wireless Telephony, etc., may send delegates, if they desire, are embodied in the form of resolutions which are sent officially by the General Secretary to administrations which, although not strictly obliged to adopt them, must necessarily take cognisance of the moral force behind them.

The work of the C.C.I., for convenience, has been divided into four distinct parts, as represented at conferences by four sub-commissions, viz.:

(1) Sub-Commission on General Organisation (of which the President has hitherto been the President of the C.C.I.—at present Monsieur Milon, France)

(2) Sub-Commission on Telephone Transmission Plant (President, Colonel Purves, Great Britain)

(3) Sub-Commission on Protection of Telephone Lines from Interference by Power Lines (President, Dr. Breisig, Germany)

(4) Sub-Commission on Traffic and Exploitation (President, Mr. Van Embden, Holland)

It may be convenient to deal with the work accomplished by the C.C.I. in the order indicated by these four classes.

(1) The first, and one of the most important objects achieved has been the creation of a corporation representing all the principal countries of Europe, which, by means of periodical conferences, has put the representatives of European Administrations into close personal and friendly touch with one another. This has been found to be of the greatest value, not only in so far as the work of the C.C.I. itself is concerned, but also in regard to the day-to-day work of Administrations which, under the present intensive development of long-distance telephony, necessarily have constant relations with one another in the establishment of new international circuits and the drafting of international agreements. It has also provided a channel through which the private electrical industry and international organisations of all kinds, interested in electrical communications, may keep in touch with administrations and obtain information as to the common views of the latter in matters affecting the work of these firms and organisations.

The C.C.I. also provides a safeguard to smaller administrations, lacking in practical experience in long-distance telephony, in so far that by the adoption of the recommendations of the C.C.I., they are assured of having at their disposal the best and most modern technical advice in connection with the construction and maintenance of their telephone plant. In their dealings with contractors, they in this way obtain a large measure of independent control over tenders and proposals.

By means of the C.C.I. also, the private electrical communications industry is able to follow the views and tendencies of administrations and to know on what lines development of research and modifications of constructional plant, is likely to achieve the best results in their dealings with administrations throughout Europe.

(2) One of the earliest and most important tasks accomplished by the C.C.I. has been the drafting, in broad outline, of standard specifications concerned with all the main classes of long-distance telephone plant (cables, repeaters, loading coils, testing apparatus, etc.). In the compilation of these specifications, the object of which has been to ensure uniformity of practice throughout Europe, representatives of the private industry have invariably been consulted in order that stipulations might reasonably conform with possibilities of actual construction.

Regulations have been drawn up which have in view standard methods of maintaining and working long-distance lines (with their accessories) when these have been constructed and brought into use.

The unit of telephone transmission to be adopted by the various countries in Europe was decided provisionally at the November, 1926, Conference. A general agreement, regarding the nature and object of the transmission unit, had been reached in that it shall serve to express the ratios of apparent and real powers, voltages or currents, and that in practice the logarithms of these ratios shall be used. Since some administrations prefer to use the decimal (or Briggs) system and others the Naperian system of logarithms in expressing the unit of transmission, it was decided that, in international traffic, the unit may be expressed on the basis of either system, but no administration shall claim the exclusive use of the unit it adopts.

The controversy over the Transmission Unit, which is the one disappointing feature of the work of the C.C.I., has at any rate had the advantage of bringing the United States through the American Telephone and Telegraph Company into close relation with Europe. The American Telephone and Telegraph Company was so good as to send representatives to a meeting in November, 1925, at which the Transmission Unit controversy was one of the main topics of discussion.

Another matter of first-class importance is the decision by the C.C.I. to establish in Paris a so-called Master Standard Reference System to be used and maintained in Paris for the purpose of enabling the countries of Europe to standardise their telephone apparatus in accordance with a common, agreed datum. This Standard Reference System will be identical with that used in America. Its composition formed the topic of discussion at a special conference of a sub-commission of the C.C.I. in London in May, 1926, where it was finally decided to adopt the system which would be used in America. Through the generosity of the American Telephone and Telegraph Company, the European Master Standard Reference System is being constructed and supplied as a free gift to the C.C.I. by that Company and it is expected that this system will be installed in Paris this Autumn.

Amongst the numerous other questions dealt with and on which decisions have been taken, may be mentioned the construction of a special type of underground cable for the purpose of interconnecting broadcasting centres in Europe. The possibilities of carrier current telephony, and the co-existence in the same cables of telegraph and telephone circuits are also under discussion and will be dealt with at the next conference of the C.C.I. to be held next September in Como which is to be the scene of numerous technical conferences on the occasion of the Centenary of the death of Volta. At this conference will also be discussed the question of unifying systems of loading telephone cables, with a view if possible to arriving at such a uniform system as will provide for future very long circuits without the necessity of making subsequent changes when circuits are extended.

(3) A very important part of the work accomplished by the C.C.I. has been the formulation of what has been termed "Directives" (guiding principles) to be adopted with a view to protecting telephone lines from interference by adjacent high power plant. In this connection it has been necessary to discuss matters in common with the electric power industry and the International Union of Railways. There are several points still in dispute in this connection, owing to the fact that the railways and the producers and distributors of electric power current consider the restrictions which it is proposed to impose on them by administrations are too severe. To get over this difficulty, it has been arranged to carry out a programme of tests to be conducted in various countries jointly by administrations and the electric power industry, in order that it may be verified whether or not the limits proposed by the C.C.I. are reasonable. The discussions on this question of protection have involved a great deal of elaborate and highly scientific work, the results of which as incorporated in the publications of the C.C.I. will be of great general interest. With this work has been associated investigations of the questions of the protection of telephone lines from corrosion due to electrolysis and chemical action.

(4) In addition to the engineering questions referred to above, which form the subject of discussion and decision by the C.C.I., advantage has been taken of the presence of representatives of most European countries at the con-

ferences of the C.C.I. to discuss questions relating to traffic and the best means of working long-distance circuits from that point of view. In telephone enterprises, like other commercial undertakings, the question of the charges to be made to the public is of course vital, but the actual rates to be charged for calls on long-distance lines in Europe have to be settled by direct agreement as the result of bargaining between the administrations concerned. Certain principles, however, have been settled as a result of discussions at the C.C.I. conferences on a number of points, such as the following: minimum traffic to be assured to transit countries in the establishment of new lines; determination of the number of calls to be allowed on any given circuit; the degree to which tariffs varying according to the hours of the day should be adopted; the number of circuits to be served by one operator; the decentralisation of traffic by the creation of zone centres; the preparation, say by telegraph, of calls; the sub-division of three minute units; and the admission of subscription calls.

The C.C.I. has also been used in this connection for the purpose of compiling statistics relating to actual costs in the construction of plant (as a basis for fixing charges) and of statistics for the purpose of estimating future traffic. The C.C.I. as a dependent of the International Telegraph Union also discusses questions arising out of the regulations with regard to telephone tariffs and traffic arising out of the "Service Regulations" laid down by the conference of the International Telegraph Union. The personal touch established between representatives of the Traffic Departments of the various administrations has been of particular value.

In addition to the above brief summary of what the C.C.I. has done and is doing may be mentioned the useful, miscellaneous functions which it has fulfilled in the way of centralising information of all kinds relating to long-distance telephony. Articles appearing in various languages in the technical press are translated into French (the official language of the Committee) and circulated. A vocabulary of telephone technical terms is being prepared.

The difficulties of working the telephone system of Europe as a whole are considerable, particularly in regard to the vital question of establishing some kind of unity of control. Europe is divided into a large number of more or less water-tight compartments, representing countries in various stages of development, possessing different ideas, different languages and different methods of work. The administrations which have to work telephone systems within the various political boundaries are responsible to their several parliaments and the ministers concerned are liable to change with their governments. In these circumstances, it is very difficult to induce the heads, for the time being, of the different States to undertake anything in the nature of risks normally taken by every commercial undertaking in connection with the outlay on expensive plant, from which the revenue is essentially problematic. When these difficulties are borne in mind and the post-war political conditions in Europe are kept in view, it will probably be admitted that the C.C.I. has fulfilled and is fulfilling a very useful function.

Paris-Strasbourg Cable

European Engineering Department, International Standard Electric Corporation

Introduction

An outstanding event from the viewpoint of European international long distance telephony was the completion in September, 1926, of the Paris-Strasbourg toll cable provided by the French Government. The cable is 494 kilometers in length and traverses several important industrial areas, such as Champagne, Lorraine and Alsace—the first famous for its wines, the second for its heavy industries and the last for its agricultural produce. In addition to providing communication between Paris and the districts mentioned, international telephone traffic is dealt with by connections from Paris to: England and Belgium; northern and central Germany, by way of Nancy and Strasbourg; and Switzerland and Italy, through Selestat. Some of the circuits involved are installed in underground cables, while others which at present are in the form of open wire lines probably will be placed underground in the near future. The maps of France and Europe (Figures 1 and 2) show the cable route and give some indication of the importance of the new system in the European communication network.

At the end of 1923, the contract for the supply and installation of a loaded and repeatered underground telephone cable was placed with Société Anonyme, Lignes Télégraphiques et Téléphoniques, concessionaires in France of the International Standard Electric Corporation for the manufacture of long distance telephone cables and the installation of complete toll cable systems. That concern manufactured and installed all the cable and also installed the loading equipment which was manufactured by Le Matériel Téléphonique, the French Associated Company

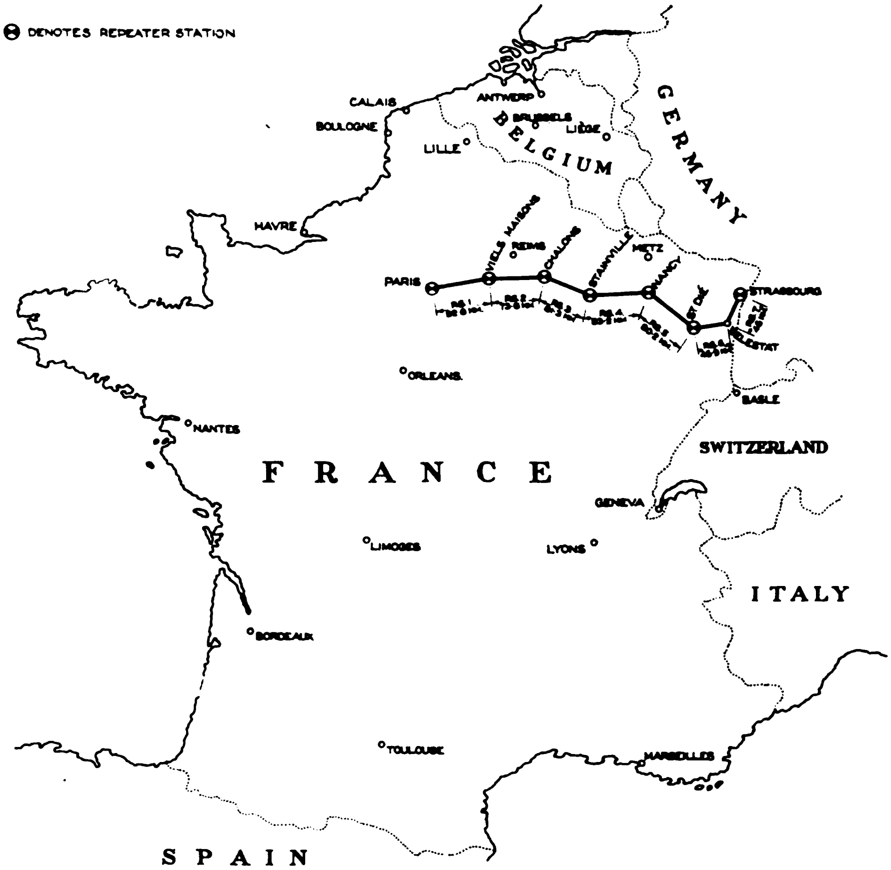


Figure 1—Map of France Showing Paris-Strasbourg Cable Route

of the International Standard Electric Corporation.

Immediately after the closing of the contract, the work of manufacturing the cable and accessories was started, and schools were established for the training of the personnel required. These schools were maintained for over two months, and the first lengths of cable were laid in May, 1924. The cable laying was completed by the end of 1925 and jointing and testing as well as installation of the loading coils followed so closely that by the end of January, 1926, all work on the system was finished with the exception of the repeater installation. By April, 1926, fifty circuits were brought into operation, and by September of that year the whole system had been handed over to the French Administration.

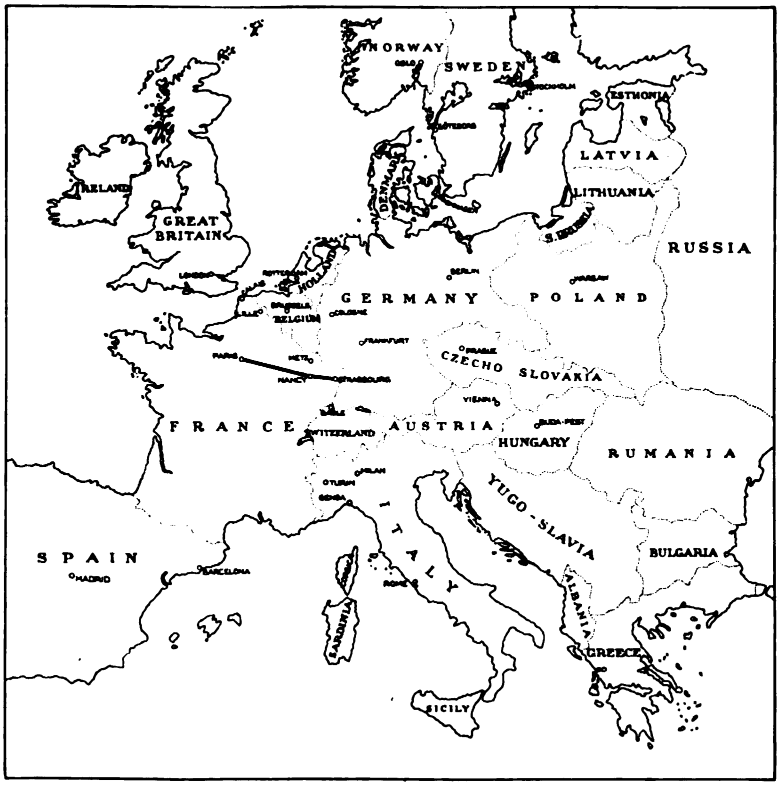


Figure 2—Map of Europe Showing Route of Paris-Strasbourg Cable

General Description

The system which it is proposed to describe in this paper is a loaded cable between Paris and Strasbourg, provided with seven repeater stations. Figure 1 indicates the route followed by the cable and shows the spacing of the repeater stations. The route was chosen after a detailed study of the possible sources of interference in the districts to be traversed and, as finally selected, gives the desired degree of separation between the cable and electric power lines or railways. To reduce to a minimum the danger of wilful or accidental damage, it was decided to lay the cable underground throughout the route. In the open country, the cable is protected by an armouring of steel tape and laid direct in the ground, the average depth of the trench being sixty centimetres, but when crossing villages or other exposed localities the depth was increased to eighty centimetres, and in addition a warning strip of wire netting was placed twenty centimetres above the cable. Where the depth was insufficient to afford natural protection, the cable was placed in Zores iron troughing which, in localities of exceptional shallowness, was encased in concrete. When traversing main roads and level crossings, the cable was pulled into iron piping. In the larger towns plain lead covered cable pulled into ducts of concrete block construction was used, and in Paris the cable was placed in a special cable subway.

On the main route between Paris and Strasbourg, two sizes of cable, having both telephone and telegraph quads, are employed. The telegraph quads are in the centre of the cable and screened from the telephone quads by means of a layer of aluminum tape. From Paris to Selestat, a distance of 450 kilometres, the cable consists of

66 quads of 0.9 mm. conductors	for telephone working
16 quads of 1.3 mm. conductors	
12 quads of 1.3 mm. conductors	for telegraph working

and, from Selestat to Strasbourg, a distance of 44 kilometres, of

42 quads of 0.9 mm. conductors	for telephone working
22 quads of 1.3 mm. conductors	
7 quads of 1.3 mm. conductors	for telegraph working

The cross sections of these cables are shown in Figures 3 and 4.

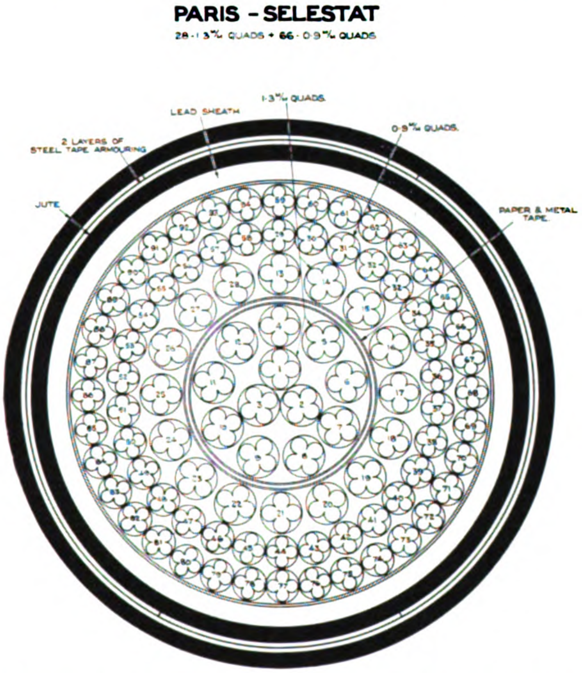


Figure 3—Cross Section of the Paris-Selestat Cable

Although blasting with dynamite was found necessary at a few points where the ground to be traversed was very rocky, the excavation of the trenches was performed almost entirely by hand. Figure 5 shows a machine employed for placing the cable in the trench.

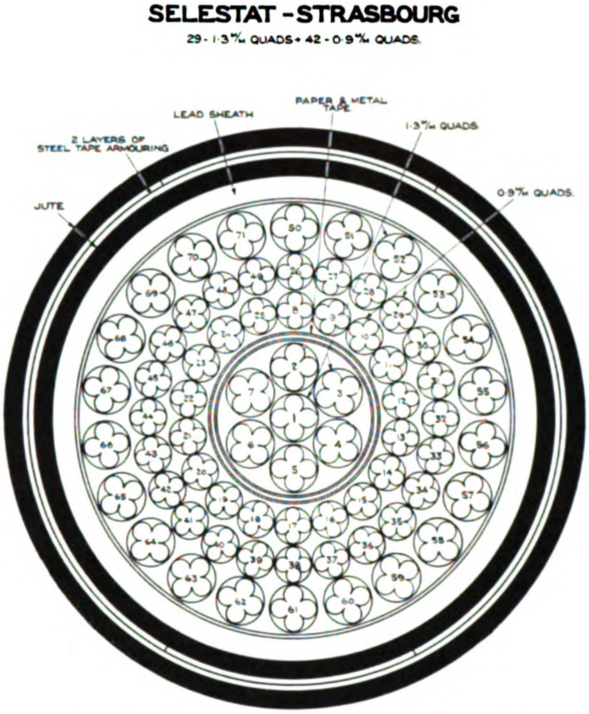


Figure 4—Cross Section of the Selestat-Strasbourg Cable

Tests were made during installation in order to reduce unbalances by the cross-splicing method to values sufficiently low to ensure satisfactory overall results. These tests included capacity unbalances, unbalances to earth, and capacity deviation; in addition, tests such as loop resistance, resistance unbalance and insulation resistance were made as a check on the installation work.

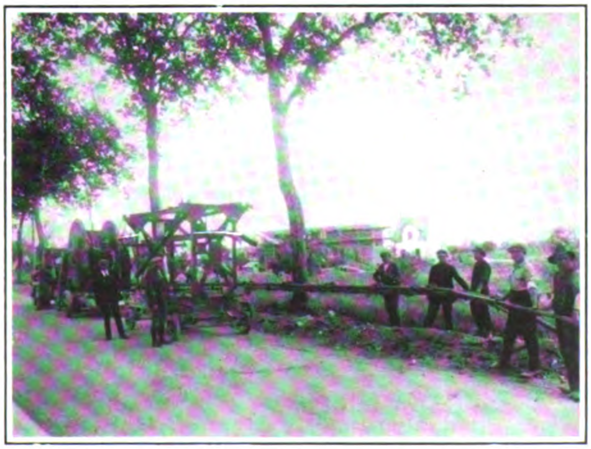


Figure 5—Cable Placing Machine

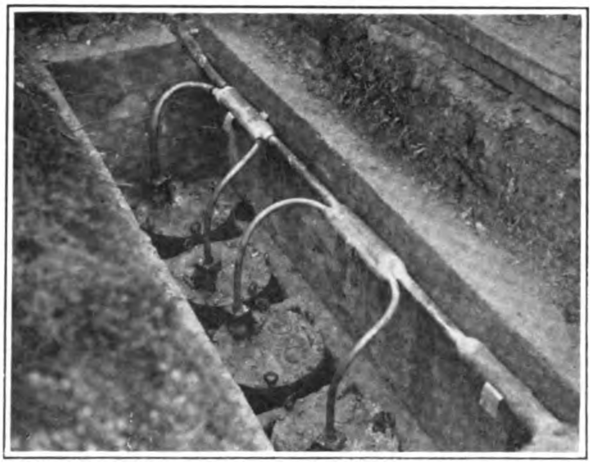


Figure 6—Loading Coil Cases Installed in a Manhole

Two types of loading are provided: viz., H-177-107 and H-44-25, the letter H signifying a spacing of about 1.8 kilometres, the first figure the inductance in millihenries of the side circuit coils, and the second figure that of the phantom circuit coil. The type of loading coil case is illustrated partially in Figure 6, from which it will be seen that a single stub is fitted to each case, thus enabling the coils to be connected to the cable without undue congestion of joints. This is particularly important where the number of cases to be installed is large.

Figure 7 shows a loading coil case being lowered—from a special type of motor lorry conveyor—into the manhole (Figure 6), which is of simple and economical design. In addition to accommodating the four loading coil cases required to load the telephone quads, the manhole provides space for the fifth case which will be required if it should be decided to load the telegraph quads.

Joints in the armoured cable other than at loading points are protected by means of split couplings of cast iron buried directly in the earth. Concrete jointing chambers are used for joints made in unarmoured cable when passing through towns.

The cable is designed to provide three types of circuits:

(a) 2-wire loaded H-177-107 for the shorter national circuits.

(b) 4-wire loaded H-177-107 for long distance national traffic.

(c) 4-wire loaded H-44-25 for international traffic.

The total number of circuits at present in operation is about 200, among which there are many important long distance circuits.

Repeater Equipment

There is a total of seven repeater stations on the Paris-Strasbourg cable route, the principal items of repeater equipment at each station being as follows:

	4-Wire Repeaters		2-Wire Repeaters		Voice Frequency Ringers		4-Wire Terminating Sets	
	Initial	Ultimate	Initial	Ultimate	Initial	Ultimate	Initial	Ultimate
Paris	75	84	..	..	94	140	69	103
Viels-Maisons	31	79	36	51	..	..	..	..
Chalons	75	84	..	..	5	7	..	..
Stainville	31	79	36	51	..	..	3	3
Nancy	75	89	1	7	22	24	8	8
St. Die	30	63	37	46	4	9	4	20
Strasbourg	26	26	5	5	31	32	25	26
Totals	343	504	115	160	156	212	109	160

At Paris, Nancy and Strasbourg, the existing telephone buildings are used for the repeater equipment, while at the remaining stations special buildings were constructed which not only provide accommodation for the repeater equipment and power plant but in most cases living quarters for the maintenance staff.

The layout of the equipment of the repeater

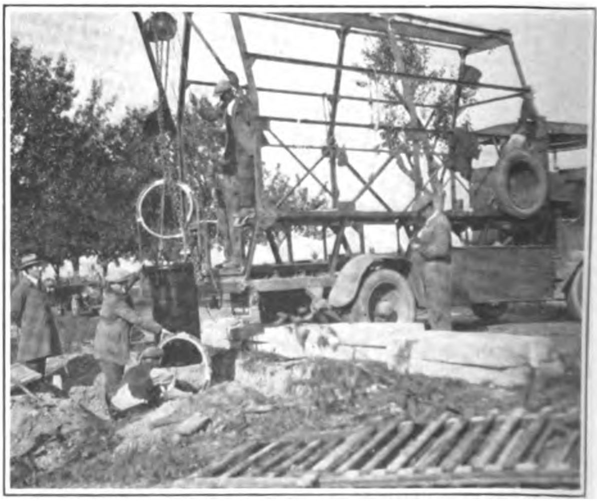


Figure 7—Motor Lorry for Transporting and Lowering Loading Coil Cases into Position

stations was completed in 1924 and embodied the best then known practice, the underlying aim having been to provide the maximum possible flexibility in the arrangement of the apparatus so that any circuit or combination of apparatus might be quickly set up or modified. With this end in view, the apparatus was assembled in groups of the same type, each group having been terminated at the distributing frame for connection by means of "jumper" wires into the required circuit combinations. Emergencies and unforeseen traffic demands can thus easily be met by simple changes in the jumper wiring.

An article by Mr. A. B. Hart, dealing with the London-Glasgow Trunk Cable,[1] describes repeater station equipment which is very similar to that installed on the Paris-Strasbourg cable and it, therefore, seems unnecessary to enter into a detailed description of this equipment in the present instance. It may be of interest, however, to touch upon certain points of difference, and, in particular, the method of connecting the main cable circuits to the repeaters.

The main cable is terminated at each repeater station by splicing it at a convenient point inside the station to two or more silk and cotton insulated lead covered cables which, in turn, are connected to protectors on the combined distributing frame. From the protectors the cable circuits are cross-connected by means of jumper wire to terminal blocks on the vertical side of the frame; they then are run through lead covered cable to the toll test board (Figure 9) and thence to the repeater equipment through jacks.

The toll test board, which is provided with testing equipment consisting of voltmeter and Wheatstone bridge testing circuits, as well as facilities for talking and ringing on the cable circuits, is so designed that routine tests can be made quickly on any cable circuit. It also provides a rapid means for bringing into service, when necessary, spare circuits or equipment.

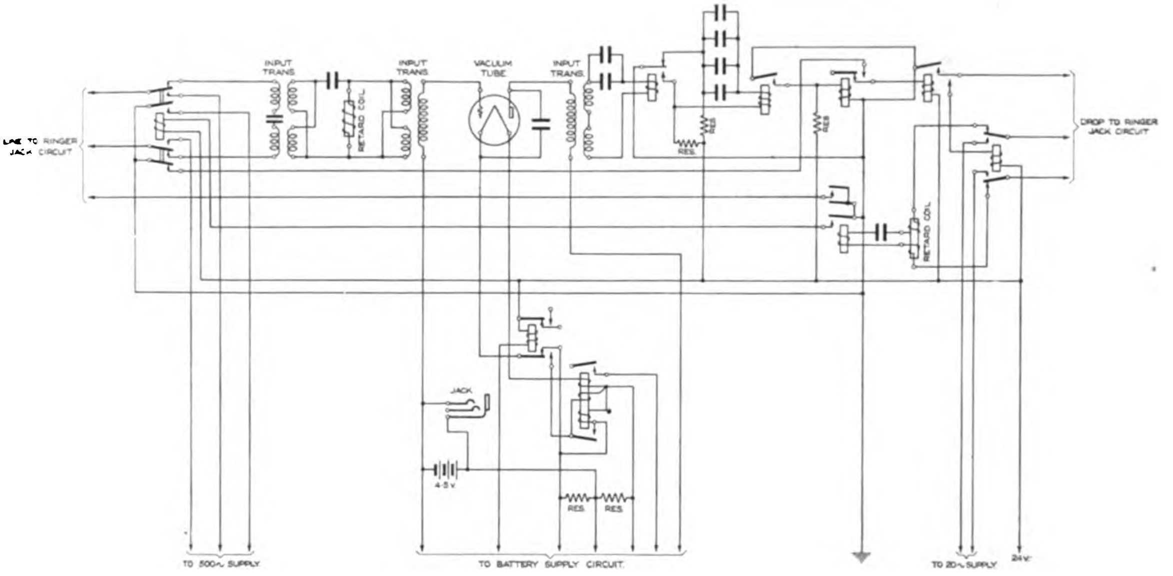


Figure 8—Voice Frequency Ringer—Circuit Schematic

While the ringing supply in the Paris-Strasbourg cable is similar to that described in the case of the London-Glasgow cable, there is a difference in the ringer panels. Figure 8 is a circuit schematic of the panel employed in the Paris-Strasbourg cable. The circuit consists of the following parts:

1. An input circuit tuned to 500 cycles.
2. A vacuum tube rectifier.
3. A 20-cycle tuned circuit operating from the output of the vacuum tube.
4. A train of direct current relays.

The train of direct current relays has a time delay element and this feature, combined with

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[1] "The London-Glasgow Trunk Telephone Cable and Its Repeater Stations," A. B. Hart, ELECTRICAL COMMUNICATION, Vol. 5, October, 1926.

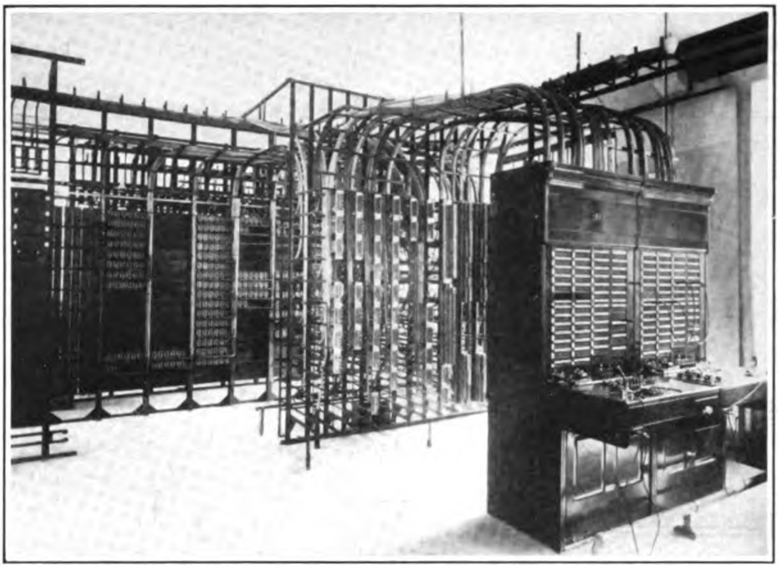

Figure 9—Toll Test Board, Distributing Frame and Repeating Coil Rack

the use of 500-cycle and 20-cycle tuned circuits, renders the panel immune from false operation due to voice current, also switch-hook and line disturbances. The vacuum tube employed has a very high amplification factor. This characteristic and the general arrangement of the circuit results in a very sensitive ringer. The panel will operate satisfactorily over a circuit of 15 TU. with a sending current of 2.0 milliamperes for the uninterrupted portions of the 500-cycle ringing current. The input impedance is very high and causes an inappreciable bridging loss to the circuit at all frequencies. In the case of 2-wire circuits it does not require balancing nor does it reduce the balance of the circuit to a noticeable extent. The filaments of the eight vacuum tubes of the ringing equipment are operated in series from the station 22½ volt battery. If any tube burns out, an alarm is operated and an equivalent resistance is inserted automatically in the place of its filament so that the operation of the remaining ringers is not affected.

The floor plan (Figure 12) illustrates the gen-

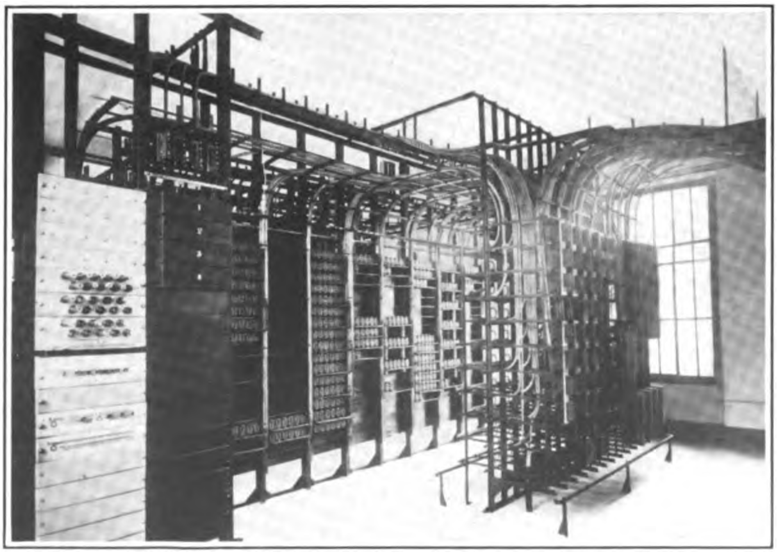

Figure 10—Fuse Panel, Distributing Frame and Repeating Coil Rack

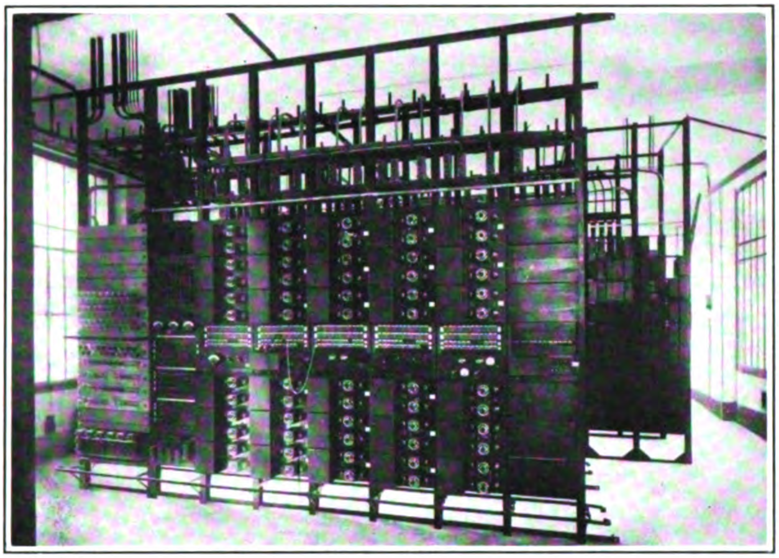

Figure 11—Four-wire Repeater Rack

eral arrangement of the repeater equipment. Figures 9, 10 and 11 show the equipment at a typical repeater station. The toll test board, combined distributing frame, and repeating coil rack are closely associated, so that the cable-runs from the point of entrance of the cable to the repeating coils may be as short as possible, in order to keep the danger of crosstalk between phantom and side circuits at a minimum. Adequate gangways are provided and space is reserved for future extensions. A transmission testing table is furnished and arranged to accommodate the portable transmission and impedance measuring apparatus used in making the line transmission tests and other special tests not provided for in the routine testing equipment of the station.

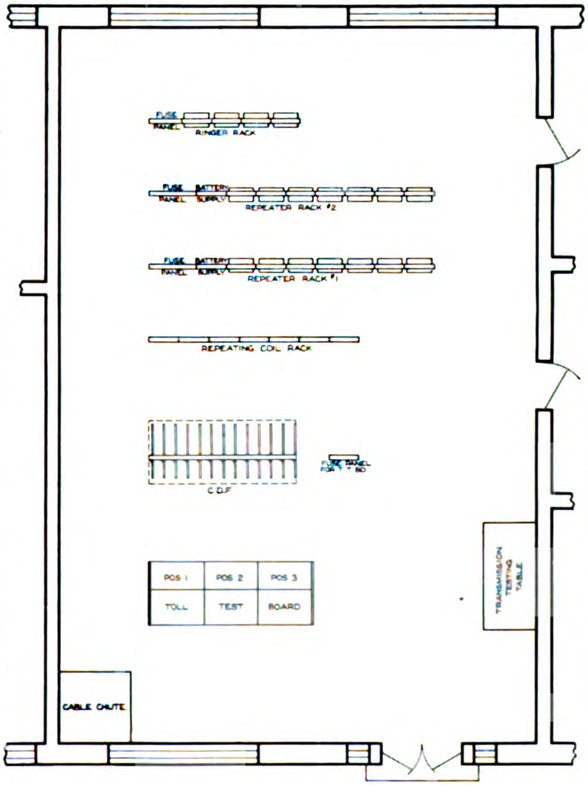

Figure 12—Repeater Station Apparatus Room Floor Plan

At all the stations, with one exception, outside power supply is available. Duplicate filament, plate and grid batteries are provided. For charging the filament batteries, ordinary commercial type generators are employed. With the aid of a noise filter especially developed for this purpose, it has been found possible to use commercial type machines for "floating" the filament batteries of repeater stations without appreciable noise on the toll circuits. As the twenty-four hour service drain is at present small, a "partial floating" routine is adopted. This routine consists in floating the battery on discharge during the day while the other battery is being charged. It secures the close regulation of voltage necessary for repeaters operating in tandem, together with economy in the size of cells and in power costs. In the case of the plate batteries, a charge-discharge routine is employed. For charging the plate batteries, two generators are furnished. The grid batteries are charged from the filament battery through a suitable resistance.

Duplicate sets of 20-cycle ringing machines are provided at each station; and, in addition, at those stations where the voice frequency circuits terminate, duplicate sets of voice frequency ringing generators (500 cycle) are installed.

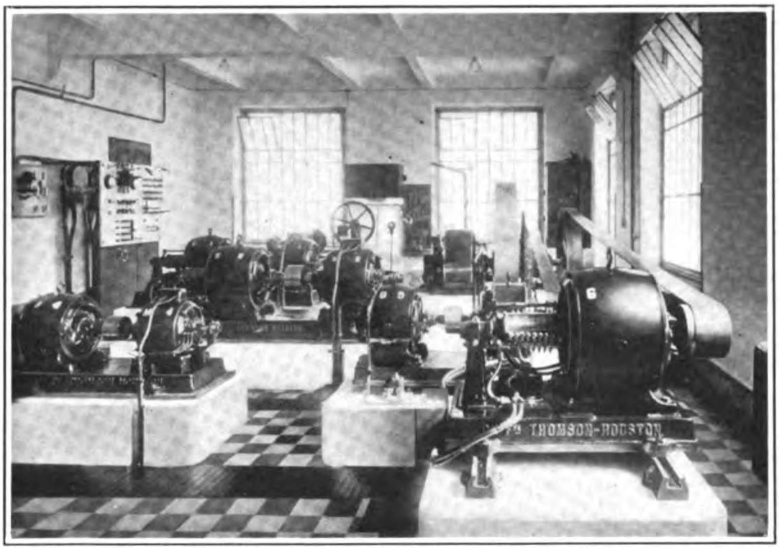

Figure 13—General View of Power Room

Figures 13, 14 and 15 show typical power plant arrangements.

In the case of the station at which no outside supply is available, all the batteries are operated on a charge and discharge routine. Two cold-starting heavy oil engine sets are installed and in order to compensate for variations in battery voltage an automatic filament current regulating device is provided at the station.

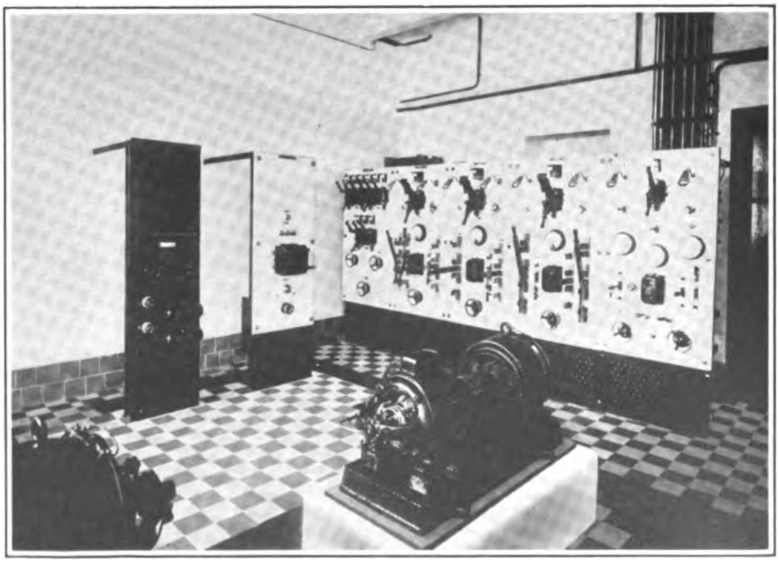

Figure 14—Power Board

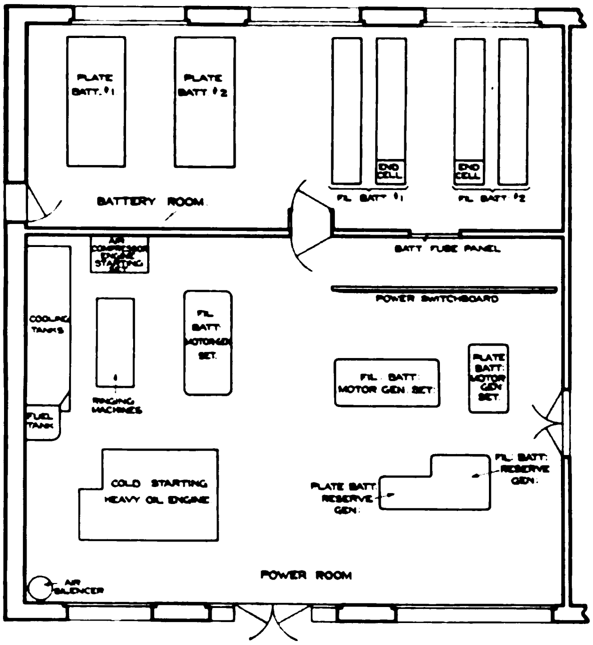

Figure 15—Floor Plan of Power and Battery Rooms

The repeater equipment was supplied and installed by Le Matériel Téléphonique acting as sub-contractors for Lignes Télégraphiques et Téléphoniques. The batteries are of Tudor manufacture while the motors and generators were made by the Compagnie des Téléphones Thomson-Houston. The oil engines were furnished by the Compagnie Française Nationale.

Transmission Tests

As soon as all the cabling and loading work on each repeater section was completed, a series of measurements was made to ensure that the cable and the loading coils were satisfactory and that the required degree of regularity had been obtained. A further object was to obtain transmission information for use during the setting up of the repeatered circuits. These tests, which included measurements of singing point, impedance, attenuation and crosstalk, are discussed briefly.

Toll line testing sets employed were, in most cases, similar to those described previously in "Electrical Communication."[2]

SINGING POINT

To determine the degree of impedance regularity obtained on the completed cable, the singing points of the circuits to be used for 2-wire working were measured from each end of each repeater section, the circuits having been balanced against the standard basic networks and building out condensers. Basic networks of each type giving average characteristics were chosen for the test, while the building out con-

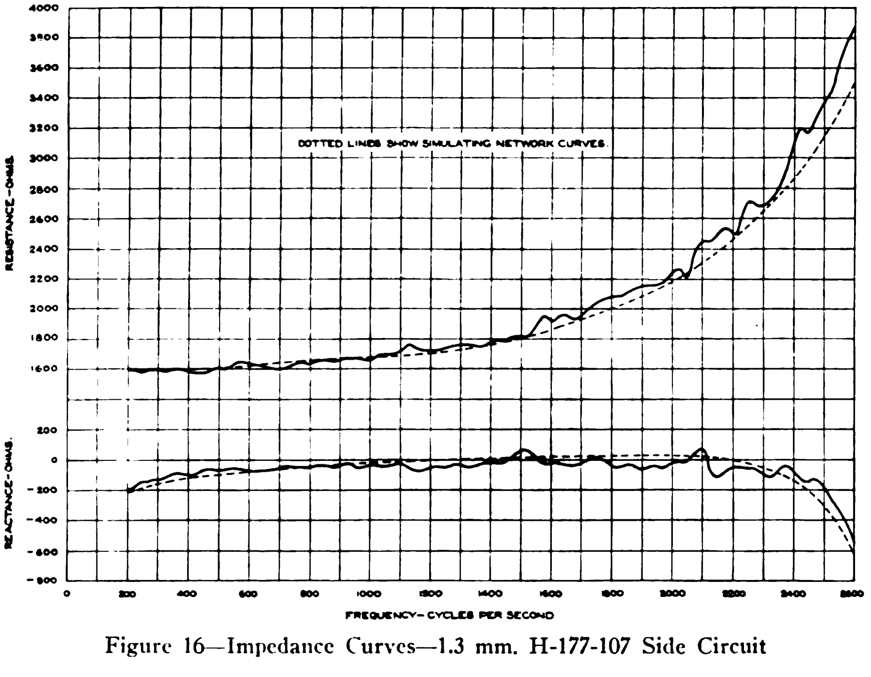

Figure 16—Impedance Curves—1.3 mm. H-177-107 Side Circuit

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[2] "Telephone Transmission Maintenance Practices," W. H. Capen, ELECTRICAL COMMUNICATION, Vol. 3, April, 1925.

TABLE I

Summary of Singing Points
1.3 mm. H-177-107 2-Wire Circuits
(The values in this table are minimum values of singing point)

	Singing Points Measured with Impedance Unbalance Measuring Set Frequency Bands Cycles per Second												Measured with Singin Point Test Set	
	200-340		340-640		640-1200		1200-1700		1700-2260		2260-2400			
	TU	% Impedance Irregularity	TU	% Impedance Irregularity	TU	% Impedance Irregularity	TU	% Impedance Irregularity	TU	% Impedance Irregularity	TU	% Impedance Irregularity	TU	% Impedance
Side Circuits														
Best Circuit......	38	3	33	4	33	4	28.5	8	27.5	9	28.5	8	31.5	5
Worst Circuit....	35	4	34	4	33	4	25.5	11	22.5	16	27.5	9	26.5	10
Phantom Circuits														
Best Circuit......	38	3	37	3	32	5	32	5	28.5	8	28.5	8	32.5	5
Worst Circuit....	38	3	32	5	29.5	7	28.5	8	25.5	11	22.5	16	28	8

TU = Transmission Units.

denser value was that which gave the highest average singing point.

These measurements were made by two distinct methods, using (1) a singing point test set and (2) an impedance unbalance measuring set.

The first of these sets is similar in operation to a 21-type repeater and the results obtained with it are an indication of the degree of balance between the circuit under test and its balancing network. Since this set has similar filter effects, both at the low and high frequencies, to those in a 2-wire repeater, the readings which it gives are related closely to the maximum gain which such a repeater would give without singing when connected to the circuit under test and its balancin network. The impedance unbalance measurin set, on the other hand, enables the balance to b measured at any desired single frequency an yields results of a more fundamental natur than the singing point test set. Results fro these tests are given in Table I.

(The figures for Percentage Impedance Irregularity refer to the radius of the circle as specified by the C. C. I. in Paris in June, 1925.)

IMPEDANCE

Impedance-frequency measurements wer made by means of the 1-B line impedance bridg

TABLE II

Summary of Average 1000 *Cycle Attenuation at* 10° *C.*

Repeater Section	1.3 m/m H-177-107				0.9 m/m H-177-107				0.9 m/m H-44-25			
	Side		Phantom		Side		Phantom		Side		Phantom	
	β per Km.	TU per Km.	β per Km.	TU per Km.	β per Km.	TU per Km.	β per Km.	TU per Km.	β per Km.	TU per Km.	β per Km.	TU per Km.
1	.0113	.0982	.0093	.0808	.0200	.1737	.0162	.1407	.0346	.3005	.0288	.2502
2	.0113	.0982	.0094	.0816	.0199	.1729	.0165	.1433	.0346	.3005	.0288	.2502
3	.0112	.0973	.0093	.0808	.0200	.1737	.0165	.1433	.0346	.3005	.0288	.2502
4	.0114	.0990	.0094	.0816	.0199	.1729	.0165	.1433	.0346	.3005	.0288	.2502
5	.0114	.0990	.0095	.0825	.0200	.1737	.0164	.1425	.0346	.3005	.0288	.2502
6 & 7	.0113	.0982	.0093	.0808	.0198	.1720	.0162	.1407	.0344	.2988	.0287	.2493

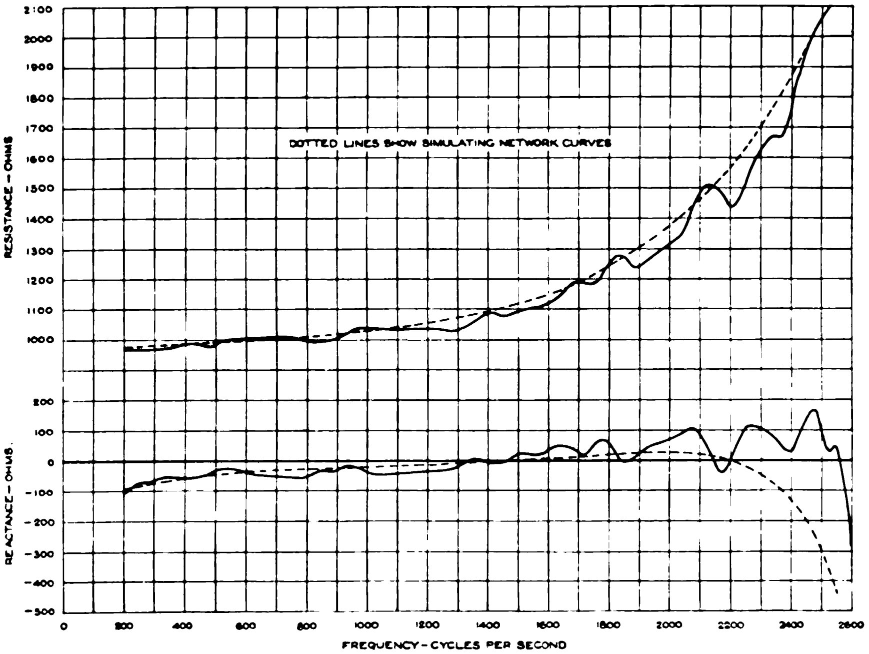


Figure 17—Impedance Curves—1.3 mm. H-177-107 Phantom Circuit

and the 4-B oscillator on representative circuits in each repeater section.

Figures 16 to 21, inclusive, show typical results of these measurements. In the first four figures, the corresponding balancing network impedance curves also are shown.

Attenuation

Measurements of attenuation at 1,000 cycles per second were made on a number of circuits in each repeater section. Table II gives a summary of these measurements corrected to 10° C., the mean ground temperature at the depth of the cable.

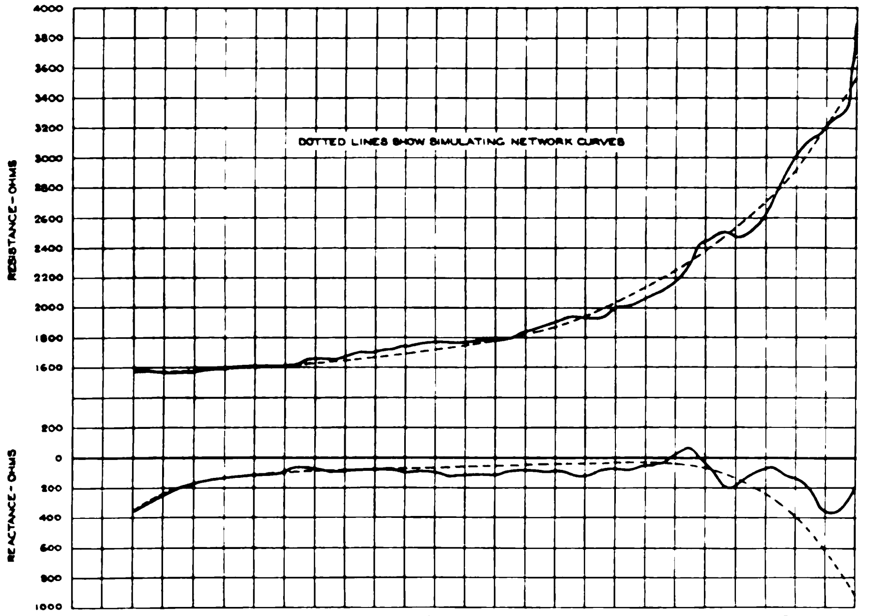


Figure 18—Impedance Curves—0.9 mm. H-177-107 Side Circuit

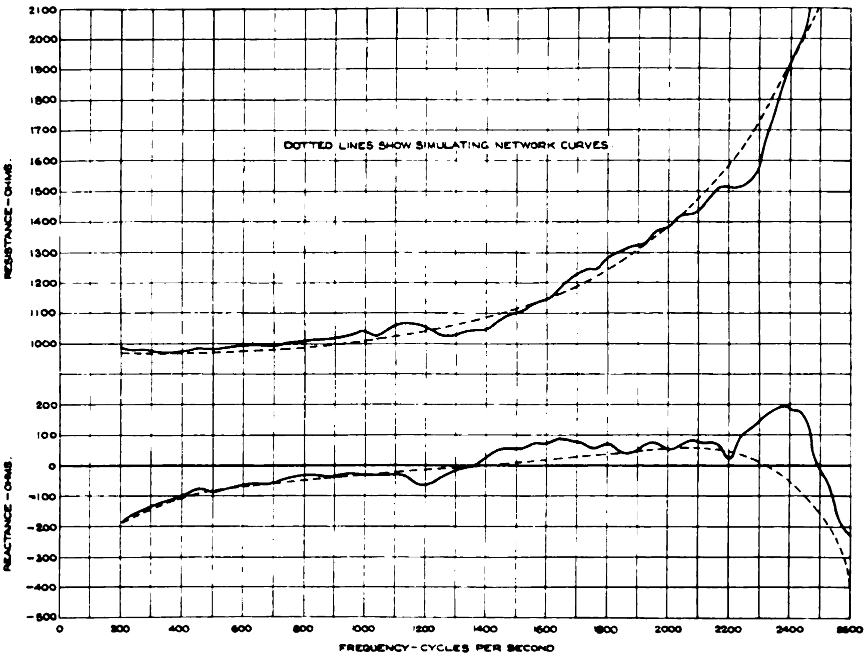


Figure 19—Impedance Curves—0.9 mm. H-177-107 Phantom Circuit

Figures 22, 23 and 24 show typical attenuation frequency curves.

CROSSTALK

Crosstalk measurements were made on each repeater section, using a complex tone as the testing current. These tests were divided into "Near-end" and "Far-end". Near-end crosstalk measurements were made on all 2-wire circuits, the tone and the measuring set having been placed together first at one end of the repeater section and then at the other. Far-end measurements were made on all 4-wire circuits.

TABLE III

Near-End Crosstalk

1.3 mm. H-177-107 Circuits

Repeater Section	Crosstalk Within Quads								Crosstalk Between Quads			
	Phantom-Side				Side-Side				Phantom-Phantom			
	Average		Maximum		Average		Maximum		Average		Maximum	
	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl
1	150	8.8	220	8.4	90	9.3	130	8.9	100	9.2	150	8.8
2	145	8.7	200	8.5	105	9.2	150	8.8	120	9.0	180	8.5
3	155	8.8	230	8.4	115	9.1	160	8.7	120	9.0	220	8.4
4	145	8.7	200	8.5	100	9.2	150	8.8	100	9.2	140	8.9
5	150	8.8	250	8.3	100	9.2	140	8.9	105	9.2	180	8.6
6 & 7	155	8.8	220	8.4	100	9.2	140	8.9	120	9.0	160	8.7

NOTE—The Average values given represent the average of the readings taken at both ends of each repeater section, while the maximum values represent the maximum reading for either end.

The values of βl given under the heading "Maximum" correspond to maximum values of crosstalk, and are therefore minimum values of βl.

the tone and the measuring set having been placed at opposite ends of the repeater section. Results of these tests are summarized in Tables III and IV.

TABLE IV

Far-End Crosstalk

Repeater Section	Circuit Group	Phantom-Side				Side-Side				Phantom-Phantom			
		Average		Maximum		Average		Maximum		Average		Maximum	
		Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl
1 (82.84 km.)	0.9 mm. H-177-107	83	9.4	210	8.5	39	10.2	90	9.3	48	9.9	180	8.6
	0.9 mm. H-44-25	32	10.4	90	9.3	9	11.6	20	10.9	9	11.6	25	10.6
2 (73.86 km.)	0.9 mm. H-177-107	73	9.5	220	8.4	48	9.9	130	9.0	56	9.8	170	8.7
	0.9 mm. H-44-25	31	10.4	80	9.4	12	11.4	40	10.1	13	11.3	40	10.1
3 (81.35 km.)	0.9 mm. H-177-107	81	9.4	230	8.3	50	9.9	130	9.0	47	10.0	150	8.8
	0.9 mm. H-44-25	36	10.2	90	9.3	8	11.7	30	10.4	9	11.6	25	10.6
4 (83.20 km.)	0.9 mm. H-177-107	69	9.6	210	8.5	44	10.0	110	9.1	50	9.9	110	9.1
	0.9 mm. H-44-25	31	10.4	90	9.3	10	11.5	30	10.4	8	11.7	20	10.9
5 (80.18 km.)	0.9 mm. H-177-107	79	9.4	210	8.5	49	9.9	100	9.2	51	9.9	120	9.0
	0.9 mm. H-44-25	39	10.2	90	9.3	13	11.3	30	10.4	11	11.5	20	10.9
6 & 7 (91.91 km.)	0.9 mm. H-177-107	74	9.5	170	8.7	42	10.1	70	9.6	53	9.8	110	9.1
	0.9 mm. H-44-25	28	10.5	60	9.7	10	11.5	15	11.1	10	11.5	20	10.9

NOTE:—Typical crosstalk-frequency results are given in Figures 25 and 26.

The values of βl given under the heading "Maximum" correspond to maximum values of crosstalk, and are therefore minimum values of βl.

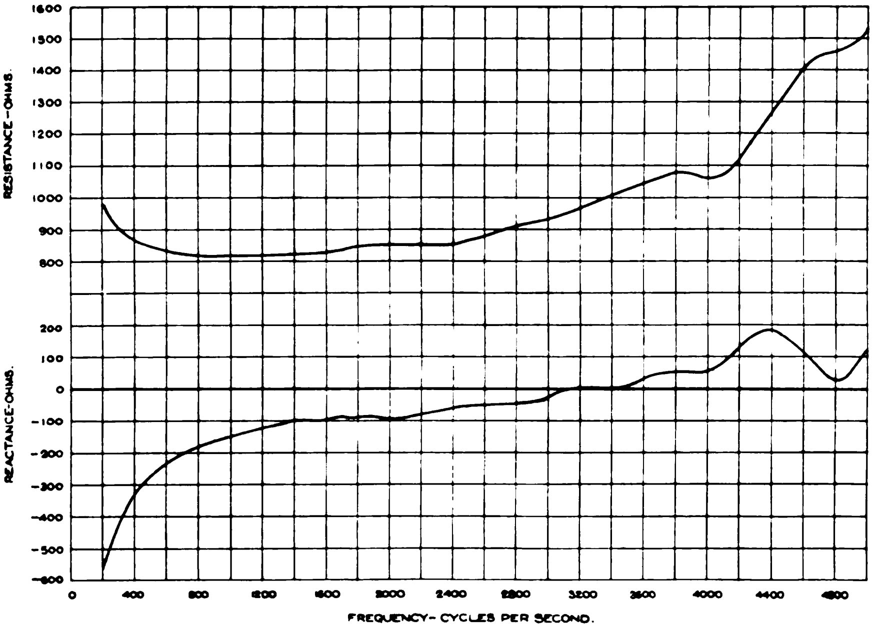


Figure 20—Impedance Curves—0.9 mm. H-44-25 Side Circuit

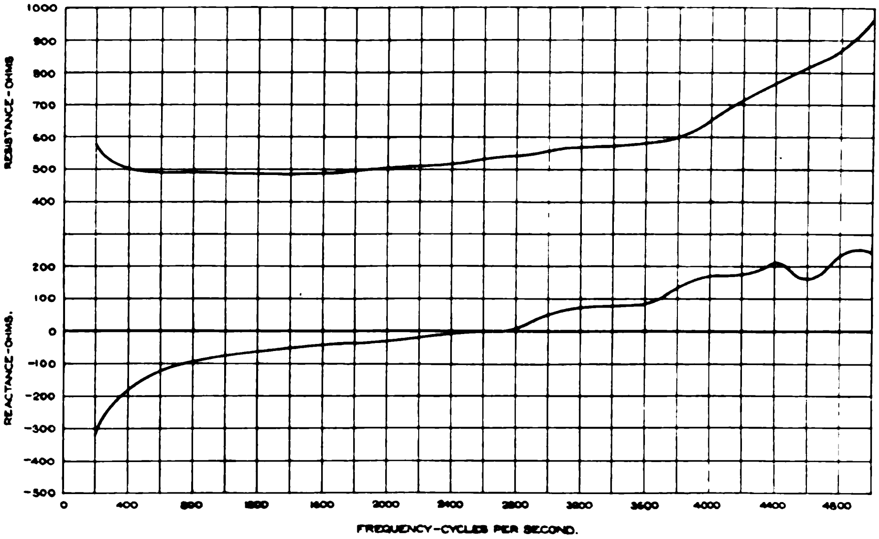


Figure 21—Impedance Curves—0.9 mm. H-44-25 Phantom Circuit

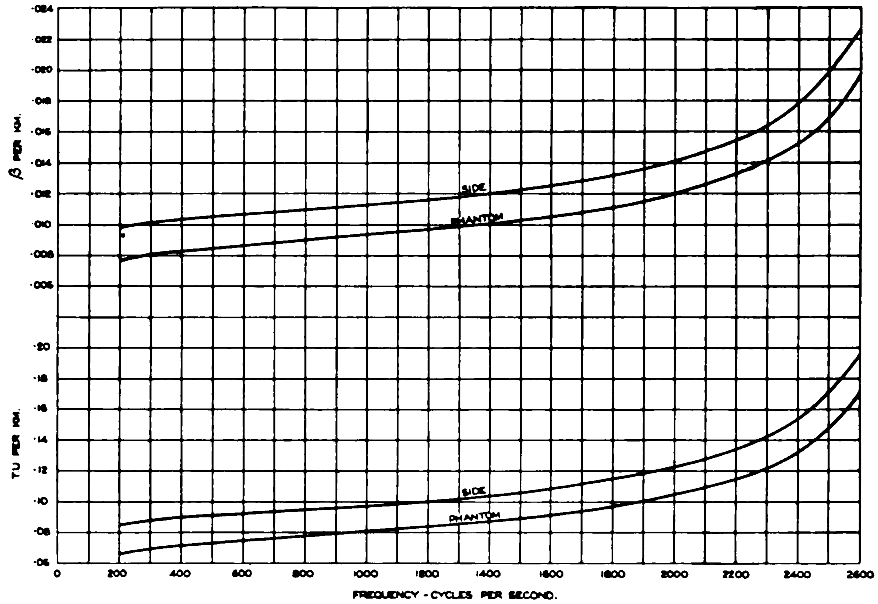


Figure 22—Attenuation—Frequency Curves—1.3 mm. H-177-107 Side and Phantom Circuits

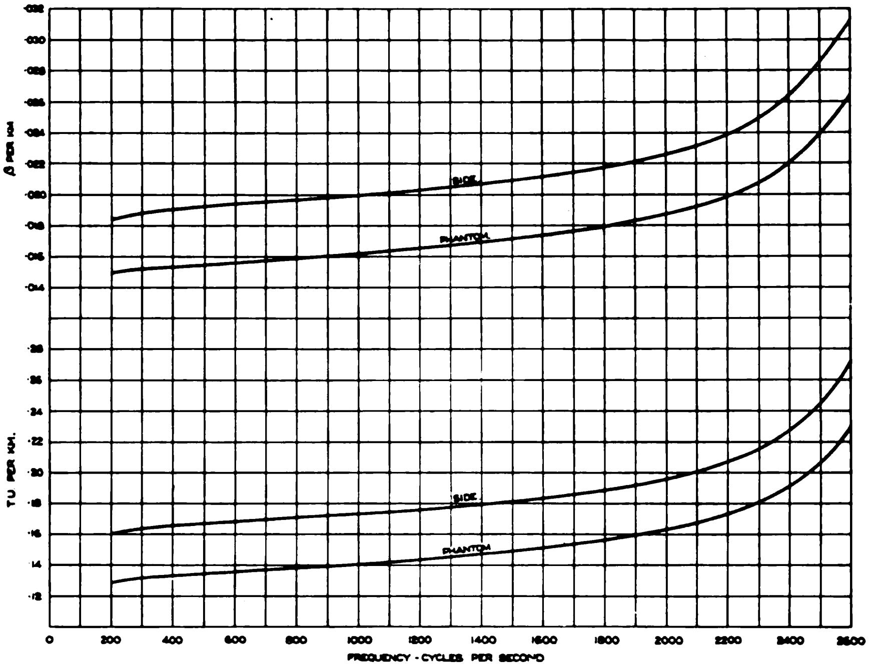


Figure 23—Attenuation—Frequency Curves—0.9 mm. H-177-107 Side and Phantom Circuits

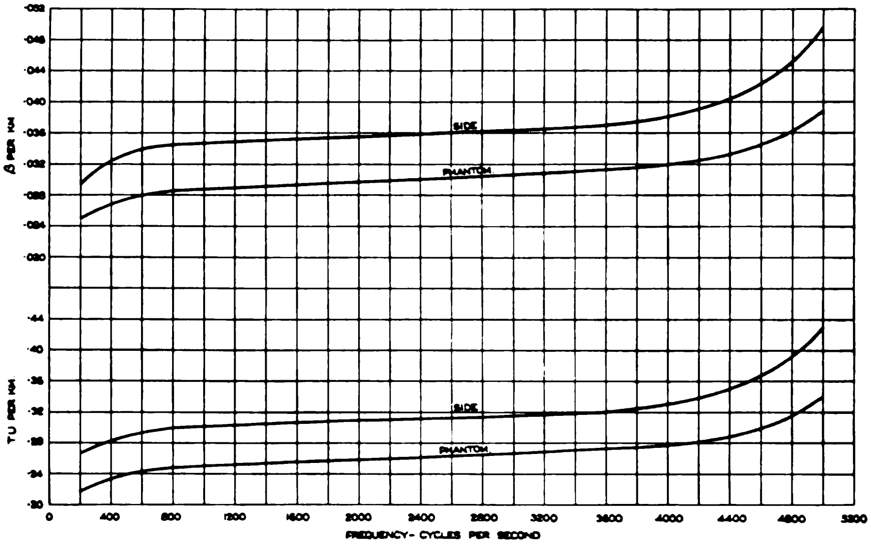


Figure 24—Attenuation—Frequency Curves—0.9 mm. H-44-25 Side and Phantom Circuits

TABLE V

Transmission Loss at 1000 *Cycles per Second*

Circuits	Direction	No. of Repeaters in Circuits	Type of Circuit	No. of Circuits	Transmission Loss					
					Maximum		Average		Minimum	
					βl	TU	βl	TU	βl	TU
Paris-Strasbourg......	West-East	4	4-wire 0.9 mm.	12	1.10	9.6	1.02	8.9	0.94	8.2
	East-West		H-177-107		1.07	9.3	0.93	8.1	0.85	7.4
Paris-Germany*......	West-East	7	4-wire 0.9 mm.	11	0.33	2.9	0.16	1.4	0.05	0.4
	East-West		H-44-25		0.26	2.3	0.16	1.4	0.07	0.6
Paris-Nancy.........	West-East	2	2-wire 1.3 mm.	9	1.07	9.3	0.98	8.5	0.87	7.6
	East-West		H-177-107		0.98	8.5	0.93	8.1	0.87	7.6
Strasbourg-Nancy.....	West-East	1	2-wire 0.9 mm.	6	1.43	12.4	1.33	11.6	1.09	9.5
	East-West		H-177-107		1.44	12.5	1.34	11.6	1.11	9.6
Paris-Reims*.........	West-East	1	2-wire 1.3 mm.	6	0.86	7.5	0.83	7.2	0.80	7.0
	East-West		H-177-107		0.82	7.1	0.80	6.9	0.76	6.6
Paris-Metz*..........	West-East	2	2-wire 1.3 mm.	9	1.10	9.6	0.96	8.3	0.83	7.2
	East-West		H-177-107		1.06	9.2	0.97	8.4	0.86	7.5
Strasbourg-Reims*....	West-East	2	2-wire 1.3 mm.	3	1.18	10.2	1.11	9.6	1.07	9.3
	East-West		H-177-107		1.09	9.5	1.05	9.1	0.95	8.3

*These values refer to the Paris-Strasbourg Cable portion of the circuit under operating conditions for the complete circuit.

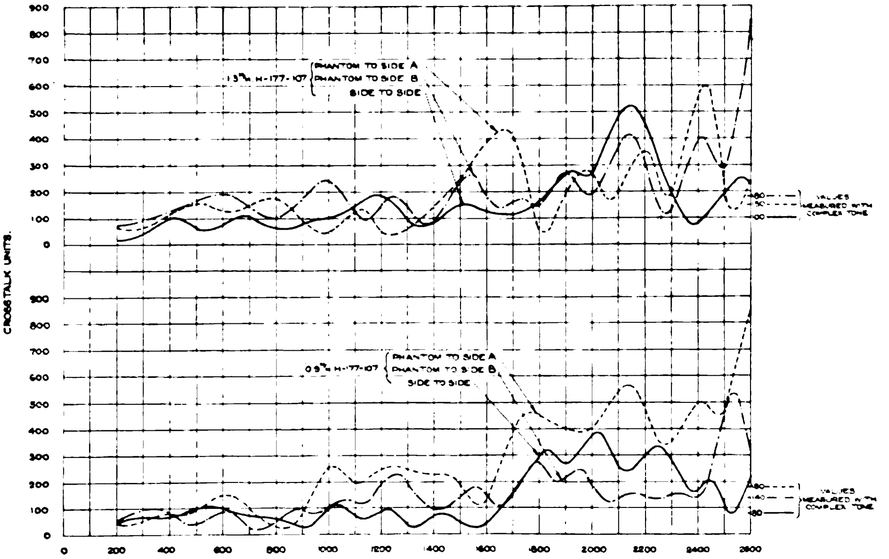


Figure 25—Near End Crosstalk—Voice Frequency—1.3 mm. and 0.9 mm. H-177-107 Circuits

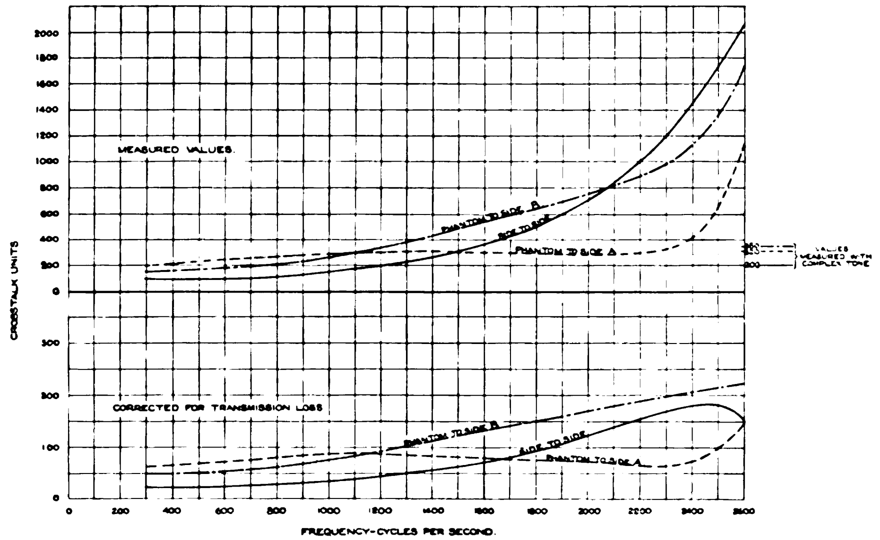


Figure 26—Far End Crosstalk—Voice Frequency—0.9 mm. H-177-107 Circuits

Overall Tests on Repeatered Circuits

All repeatered circuits, after having been set up for service, were tested for transmission loss and for crosstalk.

TRANSMISSION

Measurements of transmission loss at 1,000 cycles per second were made on all 2- and 4-wire circuits. Typical results are shown in Table V.

In addition, a number of circuits was tested for transmission frequency characteristics. Figures 27 to 30, inclusive, illustrate the results for typical circuits of each type.

From the curves shown in Figures 27 and 28, it will be observed that the transmission frequency characteristics of the 4-wire circuits when measured straight on the line were practically flat until the natural frequency of the line

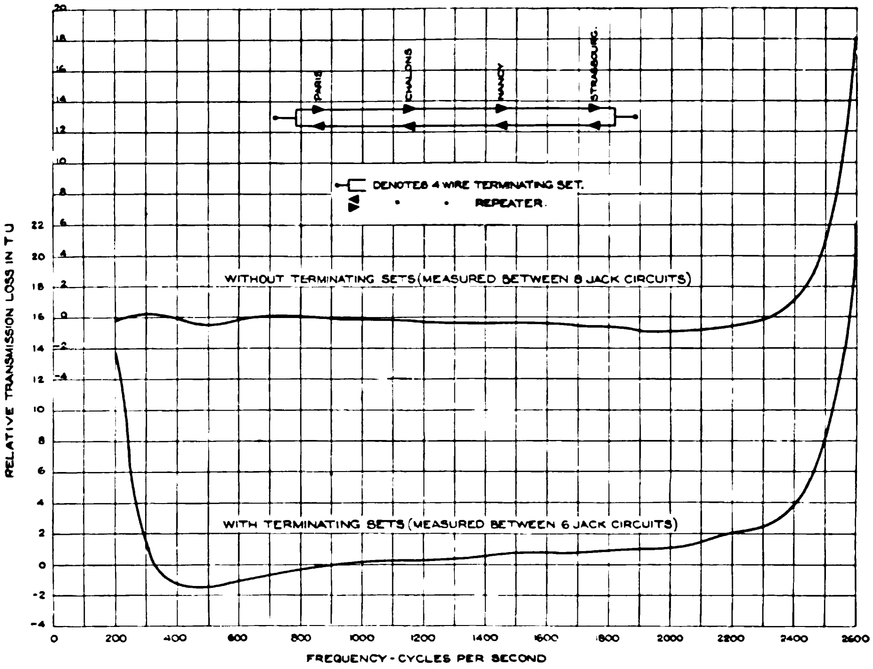


Figure 27—Overall Transmission Frequency Characteristics—0.9 mm. 4-wire H-177-107 Side Circuit

TABLE VI

Overall Crosstalk

	Crosstalk Within Quads								Crosstalk Between Quads			
	Phantom-Side				Side-Side				Phantom-Phantom			
	Average		Maximum		Average		Maximum		Average		Maximum	
	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl	Cross-talk Units	βl
FAR-END												
Paris-Strasbourg 4-wire 0.9 mm. H-177-107												
West-East	330	8.0	540	7.5	130	9.0	150	8.8	120	9.0	210	8.5
East-West	270	8.2	480	7.6	210	8.4	360	7.9	110	9.1	290	8.1
Paris-Germany* 4-wire 0.9 mm. H-44-25												
West-East	950	6.9	1500	6.5	250	8.3	330	8.0	200	8.5	350	7.9
East-West	870	7.0	1160	6.8	340	8.0	500	7.6	190	8.5	500	7.6
NEAR-END												
Paris-Nancy 2-wire 1.3 mm. H-177-107	450	7.7	900	7.0	250	8.3	250	8.3	170	8.7	500	7.6
Paris-Reims*	260	8.3	450	7.7	130	9.0	200	8.5	100	9.2	250	8.3

*These Values refer to the Paris-Strasbourg Cable portion of the circuit under operating conditions for the complete circuit.

was approached. This result was possible due to adjustment of repeater equalisation to compensate for rising line loss with increase in frequency.

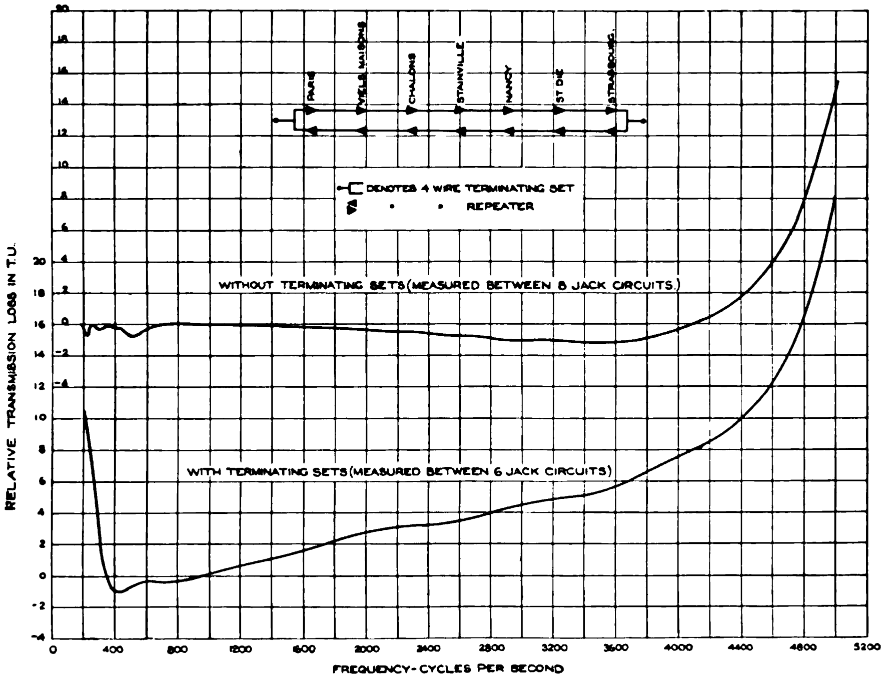


Figure 28—Overall Transmission Frequency Characteristics—0.9 mm. 4-wire H-44-25 Phantom Circuit

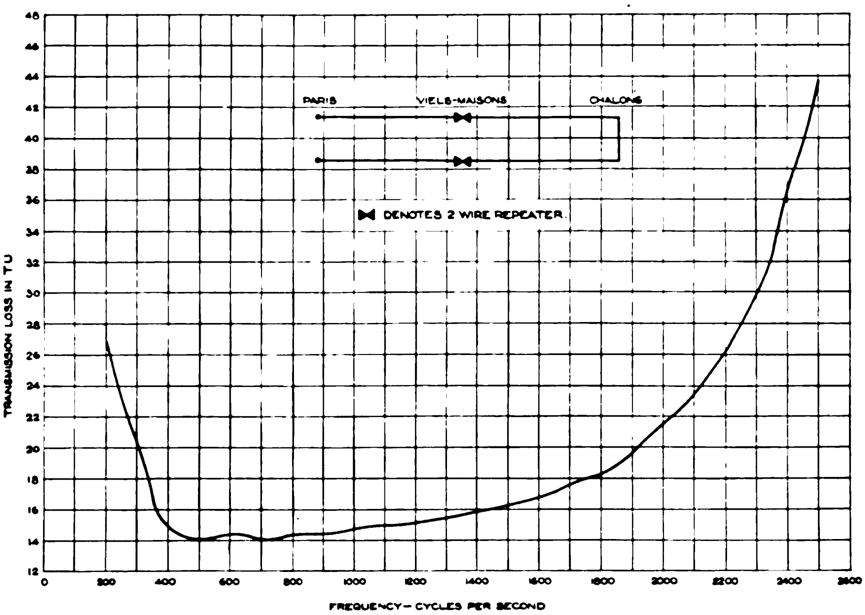


Figure 29—Overall Transmission Frequency Characteristics—1.3 mm. 2-wire H-177-107 Side Circuit

CROSSTALK

Measurements of near-end and far-end crosstalk were made on the 4-wire circuits under traffic conditions between Paris and Strasbourg.

Near-end crosstalk measurements were made on the 2-wire circuits under normal working conditions.

The results of these measurements are given in Table VI.

Conclusion

In this paper, it has been possible merely to touch briefly on the important technical features of the Paris-Strasbourg cable system. It is believed, however, that the facts enumerated are sufficient to show that the installation of this cable and its associated equipment has resulted not only in making available to France one of the most efficient toll systems in Europe but also in furnishing an important international link in the European communication network.

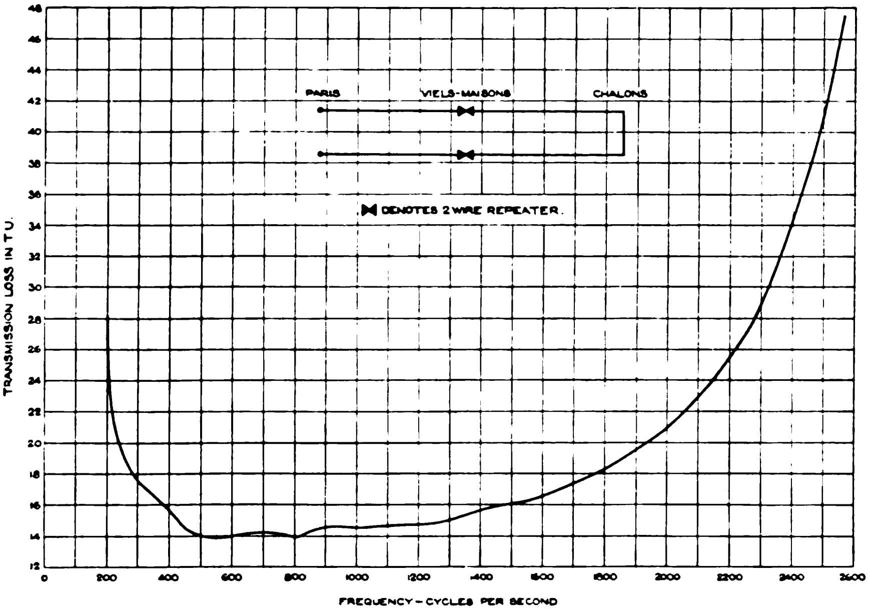
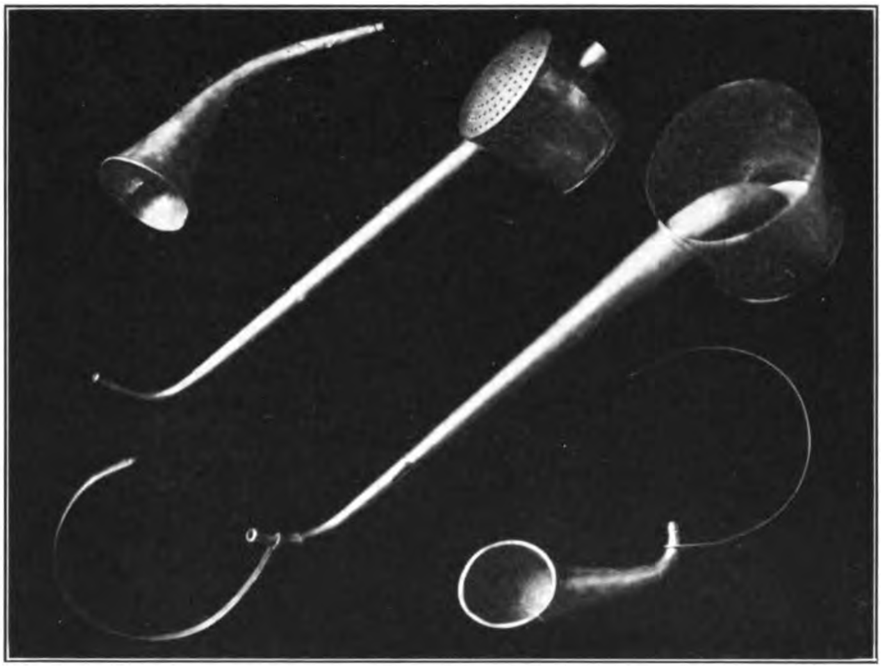


Figure 30—Overall Transmission Frequency Characteristics—1.3 mm. 2-wire H-177-107 Phantom Circuit

Beethoven's Ear-Trumpets

IN celebration of the Centenary of the great composer, the house in Bonn (Germany) where Beethoven was born has been visited this year by many musicians and others, and there has been an exhibition there of his portraits, musical instruments and manuscripts. Melancholy interest attaches to the exhibits, amongst them of ear-trumpets employed by him in the vain endeavour to overcome his deafness. These devices were of brass. It is said that he used the smaller ones for ordinary conversational purposes, and the larger ones when trying to listen to music. The mode of attachment of the apparatus to the head resembles that now adopted for certain head-phones, and the shape of the trumpet in one instance is not unlike that of the horn of a loud-speaker.

Ludvig von Beethoven was born December 17. 1770, at Bonn. His father and grandfather were both professional musicians. Ludvig began to learn music at five years of age. He early studied Sebastian Bach's works, and at thirteen he published his own first composition. In 1809, just as he had been offered the post of Kapellmeister to the King of Westphalia, he was attacked by deafness—a malady which never left him. It became gradually worse and ended at last in complete loss of hearing. He died on March 26, 1827.



Beethoven's Ear-trumpets, Exhibited at Bonn (Germany) on the Occasion of His Centenary, 1927

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1926

	Number of Telephones					
	Government Systems	Private Companies	Total	Per Cent of Total World	Telephones per 100 Population	Increase in Number of Telephones During 1925
NORTH AMERICA:						
United States	—	16,935,918	16,935,918	60.96%	14.8	863,160
Canada	208,982	935,113	1,144,095	4.12%	12.2	71,641
Central America	8,556	11,458	20,014	.07%	0.3	2,084
Mexico	2,091	52,374	54,465	.20%	0.4	3,485
West Indies:						
Cuba	545	61,569	62,114	.22%	1.8	7,200
Porto Rico	806	11,954	12,760	.05%	0.9	646
Other W. I. Places*	6,340	11,535	17,875	.06%	0.3	2,614
Other No. American Places*	85	3,936	4,021	.01%	1.1	213
Total	227,405	18,023,857	18,251,262	65.69%	11.6	951,043
SOUTH AMERICA:						
Argentina	—	189,036	189,036	.66%	1.9	15,431
Bolivia†	—	1,824	1,824	.01%	0.1	—
Brazil	632	102,352	102,984	.37%	0.3	4,420
Chile	—	35,164	35,164	.13%	0.8	4,269
Colombia	50	17,292	17,342	.06%	0.2	2,419
Ecuador†	1,691	2,827	4,518	.02%	0.2	—
Paraguay†	183	278	461	.01%	0.04	—
Peru	—	11,000	11,000	.04%	0.2	1,448
Uruguay	—	26,051	26,051	.10%	1.6	810
Venezuela	560	11,495	12,055	.04%	0.4	1,008
Other Places	2,642	—	2,642	.01%	0.5	115
Total	5,758	397,319	403,077	1.45%	0.5	29,920
EUROPE:						
Austria	153,043	—	153,043	.55%	2.3	7,902
Belgium	159,072	—	159,072	.57%	2.0	22,128
Bulgaria*	9,000	—	9,000	.03%	0.2	903
Czechoslovakia	120,548	—	120,548	.43%	0.9	4,810
Denmark	13,281♯	303,116	316,397	1.14%	9.2	8,420
Finland	—	85,000	85,000	.31%	2.4	2,000
France	737,198	—	737,198	2.65%	1.8	77,071
Germany	2,588,016	—	2,588,016	9.31%	4.1	202,839
Great Britain and No. Ireland	1,379,656	—	1,379,656	4.97%	3.0	115,632
Greece*	5,500	—	5,500	.02%	0.1	50
Hungary	78,451	—	78,451	.28%	0.9	−161
Irish Free State (March 31, 1926)	21,853	—	21,853	.08%	0.7	212
Italy (June 30, 1926)*	—	200,000	200,000	.72%	0.5	18,000
Jugo-Slavia	29,942	—	29,942	.11%	0.2	2,000
Latvia (March 31, 1926)	18,843	—	18,843	.07%	1.0	3,286
Netherlands	214,041	—	214,041	.77%	2.9	11,173
Norway	100,955‡	72,797	173,752	.63%	6.3	5,234
Poland	68,221	52,009	120,230	.43%	0.4	8,559
Portugal	2,500*	18,456	20,956	.08%	0.3	1,200
Roumania	41,755	—	41,755	.15%	0.2	7,175
Russia§	192,782	—	192,782	.69%	0.1	30,000
Spain*	—	113,000	113,000	.41%	0.5	8,000
Sweden	434,594	1,746	436,340	1.57%	7.2	18,022
Switzerland	195,525	—	195,525	.70%	5.0	6,096
Other Places in Europe*	54,750	14,040	68,790	.25%	0.8	6,000
Total	6,619,526	860,164	7,479,690	26.92%	1.5	566,551
ASIA:						
British India (March 31, 1926)	15,050	28,189	43,239	.16%	0.01	1,999
China*	82,168	35,606	117,774	.43%	0.03	5,704
Japan (March 31, 1926)	636,736	—	636,736	2.29%	1.1	92,303
Other Places in Asia*	100,883	7,954	108,837	.39%	0.1	4,172
Total	834,837	71,749	906,586	3.27%	0.1	104,178
AFRICA:						
Egypt	35,744	—	35,744	.13%	0.2	1,936
Union of South Africa♯	80,689	—	80,689	.29%	1.1	9,241
Other Places in Africa*	52,929	1,086	54,015	.19%	0.05	5,768
Total	169,362	1,086	170,448	.61%	0.1	16 945
OCEANIA:						
Australia (June 30, 1925)	362,949	—	362,949	1.30%	6.1	44,670
Dutch East Indies	37,561	3,402	40,963	.15%	0.01	1,694
Hawaii	—	18,804	18,804	.07%	6.4	1,097
New Zealand (March 31, 1926)	130,186	—	130,186	.47%	9.2	10,089
Philippine Islands	4,517	12,449	16,966	.06%	0.1	1,000
Other Places in Oceania*	2,502	530	3,032	.01%	0.2	278
Total	537,715	35,185	572,900	2.06%	0.8	58,828
TOTAL WORLD	8,394,603	19,389,360	27,783,963	100.00%	1.5	1,727,465

* Partly estimated.
♯ March 31, 1926.
‡ June 30, 1925.
§ Including Siberia and Associated Republics.
† January 1, 1925.

Telephone and Telegraph Wire of the World, by Countries

January 1, 1926

	Miles of Telephone Wire				Miles of Telegraph Wire		
	Service Operated by (See Note)	Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	52,200,000	60.72%	45.5	2,035,000	30.49%	1.8
Canada	P.G.	3,048,647	3.55%	32.6	284,121	4.26%	3.0
Central America	P.G.	37,511	.04%	0.6	19,902	.30%	0.3
Mexico	P.G.	126,645	.15%	0.8	81,876	1.23%	0.5
West Indies:							
Cuba	P.G.	188,949	.22%	5.5	10,939	.16%	0.3
Porto Rico	P.G.	25,196	.03%	1.8	1,067	.01%	0.1
Other W. I. Places*	P.G.	37,244	.04%	0.6	5,550	.08%	0.1
Other No. American Places*	P.G.	8,042	.01%	2.3	10,000	.15%	2.8
Total		55,672,234	64.76%	35.5	2,448,455	36.68%	1.6
SOUTH AMERICA:							
Argentina	P.	593,221	.69%	5.9	200,442	3.00%	2.0
Bolivia	P.	3,589†	.01%	0.1	6,986	.11%	0.2
Brazil	P.G.	265,861	.31%	0.7	97,034	1.45%	0.3
Chile	P.	53,116	.06%	1.1	45,116	.68%	1.0
Colombia	P.	22,656	.02%	0.3	15,538	.23%	0.2
Ecuador	P.G.	5,083†	.01%	0.2	4,555	.07%	0.2
Paraguay	P.G.	138†	—	0.01	2,223	.03%	0.2
Peru	P.	39,433	.04%	0.7	10,691	.16%	0.2
Uruguay	P.	46,677	.05%	2.8	6,404	.10%	0.4
Venezuela	P.G.	31,589	.04%	1.1	6,883	.10%	0.2
Other Places	G.	4,713	.01%	1.0	779	.01%	0.2
Total		1,066,076	1.24%	1.4	396,651	5.94%	0.5
EUROPE:							
Austria	G.	401,498	.47%	5.9	48,135	.72%	0.7
Belgium	G.	600,246	.70%	7.7	25,733	.39%	0.3
Bulgaria*	G.	35,000	.04%	0.7	20,000	.30%	0.4
Czechoslovakia	G.	231,805	.27%	1.6	44,298	.66%	0.3
Denmark	P.G.	771,927	.90%	22.4	9,064	.14%	0.3
Finland	P.	108,887	.13%	3.1	9,758	.15%	0.3
France	G.	2,058,832	2.39%	5.1	474,228	7.10%	1.2
Germany	G.	8,603,015	10.00%	13.5	558,987	8.37%	0.9
Great Britain and No. Ireland#	G.	5,618,346	6.53%	12.4	327,890	4.91%	0.7
Greece*	G.	7,000	.01%	0.1	30,000	.45%	0.5
Hungary	G.	239,428	.28%	2.9	51,468	.77%	0.6
Irish Free State (March 31, 1926)	G.	60,551	.07%	2.0	22,983	.34%	0.8
Italy (June 30, 1926)*	P.G.	650,000	.76%	1.6	264,000	3.96%	0.7
Jugo-Slavia	G.	86,802	.10%	0.6	55,484	.83%	0.4
Latvia (March 31, 1926)	G.	91,298	.11%	4.8	5,996	.09%	0.3
Netherlands	G.	440,000*	.51%	5.9	28,818	.43%	0.4
Norway (June 30, 1925)	P.G.	441,591	.51%	15.9	25,067	.38%	0.9
Poland	P.G.	453,712	.53%	1.6	60,005	.90%	0.2
Portugal	P.G.	69,355	.08%	1.1	19,500*	.29%	0.3
Roumania	G.	91,350	.11%	0.5	50,757	.76%	0.3
Russia‡	G.	898,137	1.04%	0.6	382,709	5.73%	0.3
Spain*	P.	225,000	.26%	1.0	83,000	1.24%	0.4
Sweden	G.	979,957	1.14%	16.2	54,503	.82%	0.9
Switzerland	G.	539,059	.63%	13.7	24,674	.37%	0.6
Other Places in Europe*	P.G.	132,786	.15%	1.6	15,813	.24%	0.2
Total		23,835,582	27.72%	4.7	2,692,870	40.34%	0.5
ASIA:							
British India (March 31, 1926)	P.G.	348,115	.40%	0.1	392,660	5.89%	0.1
China*	P.G.	194,739	.23%	0.04	84,847	1.27%	0.02
Japan (March 31, 1926)	G.	1,868,842	2.17%	3.1	176,339	2.64%	0.3
Other Places in Asia*	P.G.	220,829	.26%	0.2	110,254	1.65%	0.1
Total		2,632,525	3.06%	0.3	764,100	11.45%	0.1
AFRICA:							
Egypt	G.	134,334	.16%	0.7	26,973	.41%	0.1
Union of South Africa#	G.	283,290*	.33%	3.8	45,830	.69%	0.6
Other Places in Africa*	P.G.	107,032	.12%	0.1	129,105	1.93%	0.1
Total		524,656	.61%	0.4	201,908	3.03%	0.1
OCEANIA:							
Australia (June 30, 1925)	G.	1,526,699	1.77%	25.7	114,048	1.71%	1.9
Dutch East Indies	P.G.	183,810	.21%	0.3	20,032	.30%	0.04
Hawaii	P.	58,221	.07%	19.9	0	.00%	0.0
New Zealand (March 31, 1926)	G.	436,410	.51%	31.0	25,814	.39%	1.8
Philippine Islands	P.G.	33,906	.04%	0.3	9,521	.14%	0.8
Other Places in Oceania*	P.G.	5,469	.01%	0.3	1,351	.02%	0.1
Total		2,244,515	2.61%	3.0	170,766	2.56%	0.2
TOTAL WORLD		85,975,588	100.00%	4.6	6,674,750	100.00%	0.4

Note: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and the Government.

* Partly estimated. # March 31, 1926. ‡ Including Siberia and Associated Republics. † January 1, 1925.

Telephone Development of Large and Small Communities

January 1, 1926

Country	Service Operated by (See Note)	Number of Telephones: In Communities of 50,000 Population and Over	Number of Telephones: In Communities of less than 50,000 Population	Telephones per 100 Population: In Communities of 50,000 Population and Over	Telephones per 100 Population: In Communities of less than 50,000 Population
Austria	G.	112,664	40,379	5.0	0.9
Belgium	G.	117,879	41,193	3.8	0.9
Canada	P.G.	528,166	615,929	20.6	9.1
Czechoslovakia	G.	44,913	75,635	4.0	0.6
Denmark	P.G.	137,472	178,925	15.6	7.0
France	G.	426,955	310,243	5.0	1.0
Germany	G.	1,571,361	1,016,655	7.8	2.3
Great Britain and Northern Ireland#	G.	1,032,433	379,027	4.4	1.7
Japan#	G.	383,077	253,659	3.8	0.5
Netherlands	G.	139,924	74,117	5.4	1.5
New Zealand#	G.	46,524	83,662	9.0	9.4
Norway	P.G.	55,917	117,835	13.7	5.0
Poland	P.G.	63,913	56,317	2.2	0.2
Sweden	G.	162,964	273,376	19.4*	5.2
Switzerland	G.	85,760	109,765	11.1	3.5
United States	P.	8,659,943	8,275,975	19.8	11.7

Note: P. Indicates telephone service operated by Private Companies, G. by the Government, and P.G. by both Private Companies and the Government.

March 31, 1926.

* The majority of this development is due to Stockholm.

Telephones in United States—Distribution by States

January 1, 1926 and January 1, 1927

State	Number of Telephones: January 1, 1926	Number of Telephones: January 1, 1927
Alabama	109,512	115,451
Arizona	29,728	31,727
Arkansas	113,667	117,414
California	1,027,552	1,126,387
Colorado	170,575	176,906
Connecticut	256,813	275,169
Delaware	26,406	27,617
District of Columbia	127,977	137,327
Florida	127,594	158,065
Georgia	158,440	166,421
Idaho	51,617	53,748
Illinois	1,522,959	1,603,271
Indiana	535,426	536,671
Iowa	566,085	564,343
Kansas	380,509	387,772
Kentucky	223,444	220,105
Louisiana	118,969	130,485
Maine	127,030	128,622
Maryland	180,826	191,752
Massachusetts	808,194	843,170
Michigan	631,141	675,568
Minnesota	455,451	460,394
Mississippi	71,543	76,502
Missouri	620,492	642,092
Montana	56,221	56,870
Nebraska	284,695	285,778
Nevada	11,720	12,262
New Hampshire	79,195	81,485
New Jersey	512,048	558,211
New Mexico	19,921	20,854
New York	2,292,650	2,442,298
North Carolina	142,738	151,455
North Dakota	83,276	84,291
Ohio	1,054,426	1,078,379
Oklahoma	256,719	270,053
Oregon	169,613	178,597
Pennsylvania	1,281,314	1,333,219
Rhode Island	106,706	111,775
South Carolina	60,708	62,911
South Dakota	110,119	110,841
Tennessee	203,289	215,813
Texas	557,889	590,106
Utah	59,423	61,060
Vermont	58,357	59,854
Virginia	170,637	177,551
Washington	271,453	286,135
West Virginia	141,027	142,091
Wisconsin	482,353	499,890
Wyoming	27,471	27,410
United States	16,935,918	17,746,168

Telephone Conversations and Telegrams

Year 1925

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communica-cations	Per Cent of Total Wire Communications: Telephone Conver-sations	Per Cent of Total Wire Communications: Telegrams	Wire Communications Per Capita: Telephone Conver-sations	Wire Communications Per Capita: Telegrams	Wire Communications Per Capita: Total
Australia	295,380,000	17,773,000	313,153,000	94.3	5.7	50.4	3.0	53.4
Austria	366,730,000	3,675,000	370,405,000	99.0	1.0	54.7	0.6	55.3
Belgium	146,573,000	5,574,000	152,147,000	96.3	3.7	18.9	0.7	19.6
Czechoslovakia	191,572,000	5,141,000	196,713,000	97.4	2.6	13.5	0.4	13.9
Denmark	460,875,000	2,368,000	463,243,000	99.5	0.5	134.6	0.7	135.3
France	788,302,000	59,143,000	847,445,000	93.0	7.0	19.6	1.5	21.1
Germany	2,038,499,000	40,295,000	2,078,794,000	98.1	1.9	32.5	0.6	33.1
Gt. Britain and No. Ireland•	1,127,353,000	60,347,000	1,187,700,000	95.0	5.0	25.0	1.3	26.3
Hungary	110,721,000	4,950,000	115,671,000	95.7	4.3	13.4	0.6	14.0
Italy (1923)	361,351,000	18,457,000	379,808,000	95.1	4.9	9.0	0.5	9.5
Japan	1,964,253,000	61,585,000	2,025,838,000	97.0	3.0	33.0	1.0	34.0
Netherlands	396,319,000	5,460,000	401,779,000	98.6	1.4	53.8	0.7	54.5
Norway	295,026,000	4,094,000	299,120,000	98.6	1.4	106.8	1.5	108.3
Sweden	642,658,000	3,937,000	646,593,000	99.4	0.6	106.3	0.7	107.0
Switzerland	154,690,000	3,126,000	157,816,000	98.0	2.0	39.4	0.8	40.2
United States	22,400,000,000	215,000,000	22,615,000,000	99.0	1.0	196.4	1.9	198.3

Note: Telephone conversations include local and toll or long distance conversations. Number of telephone conversations in the United States includes completed messages only.

Telephone Development of Large Cities
January 1, 1926

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINA:			
Buenos Aires	2,310,000	104,281	4.5
AUSTRALIA:			
Adelaide	304,000	24,838	8.2
Brisbane	264,000	18,477	7.0
Melbourne	912,000	73,694	8.1
Sydney	1,039,000	87,504	8.4
AUSTRIA:			
Gratz	157,000	7,146	4.6
Vienna	1,919,000	98,226	5.1
BELGIUM:			
Antwerp	490,000	23,379	4.8
Brussels	892,000	54,798	6.1
Charleroi	184,000	4,832	2.6
Ghent	268,000	6,696	2.5
Liege	408,000	11,331	2.8
CANADA:			
Montreal	821,000	138,225	16.8
Ottawa	180,000	33,547	18.6
Toronto	633,000	154,740	24.5
CHINA*			
Canton	925,000	3,000	0.3
Shanghai	1,560,000	24,000	1.5
Tientsin	830,000	7,770	0.9
Peking	1,350,000	41,294	3.1
CUBA:			
Havana	563,000	42,860	7.6
CZECHOSLOVAKIA:			
Prague	704,000	29,049	4.1
DANZIG, FREE CITY OF	373,000	17,497	4.7
DENMARK:			
Copenhagen	755,000	121,286	16.1
FRANCE:			
Bordeaux	276,000	12,579	4.6
Lille	207,000	9,883	4.8
Lyons	580,000	18,501	3.2
Marseilles	605,000	18,528	3.1
Paris	2,995,000	255,561	8.5
GERMANY:			
Berlin	4,034,000	415,871	10.3
Bremen	296,000	27,161	9.2
Breslau	558,000	36,486	6.5
Chemnitz	334,000	20,785	6.2
Cologne	701,000	57,563	8.2
Dresden	622,000	50,139	8.1
Dusseldorf	433,000	33,919	7.8
Essen	471,000	21,273	4.5
Frankfort-on-Main	464,000	50,980	11.0
Hamburg-Altona	1,270,000	139,107	11.0
Hannover	424,000	30,897	7.3
Leipzig	682,000	57,586	8.4
Magdeburg	293,000	18,892	6.4
Munich	696,000	61,537	8.8
Nuremburg	468,000	30,633	6.5
Stuttgart	343,000	34,538	10.1
GREAT BRITAIN AND NORTH IRELAND: (March 31, 1926)			
Belfast	415,000	12,371	3.0
Birmingham	1,069,000	37,394	3.5
Blackburn	127,000	3,697	2.9
Bolton	179,000	4,655	2.6
Bradford	314,000	15,100	4.8
Bristol	390,000	13,647	3.5
Edinburgh	420,000	21,372	5.1
Glasgow	1,119,000	45,957	4.1
Hull	341,000	14,904	4.4
Leeds	482,000	16,742	3.5
Liverpool	1,116,000	46,556	4.2
London	7,406,000	488,499	6.6
Manchester	1,055,000	49,944	4.7
Newcastle	458,000	15,961	3.5
Nottingham	293,000	11,955	4.1
Plymouth	210,000	4,820	2.3
Sheffield	491,000	15,019	3.1

* Partly estimated.

Telephone Development of Large Cities—(*Concluded*)

January 1, 1926

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
HUNGARY: (January 1, 1925)			
Budapest	953,000	48,680	5.1
Szegedin	113,000	2,083	1.8
IRISH FREE STATE: (March 31, 1926)			
Dublin	406,000	12,917	3.2
ITALY: (June 30, 1923)			
Milan	714,000	17,992	2.5
Naples	785,000	6,786	0.9
Rome	648,000	14,261	2.2
Turin	509,000	7,953	1.6
JAPAN: (March 31, 1926)			
Kobe	652,000	24,642	3.8
Kyoto	698,000	24,181	3.5
Nagoya	802,000	21,629	2.7
Osaka	1,187,000	76,845	6.5
Tokio	2,069,000	121,856	5.9
Yokohama	412,000	13,456	3.3
LATVIA: (March 31, 1926)			
Riga	340,000	10,624	3.1
NETHERLANDS:			
Amsterdam	718,000	39,644	5.5
The Hague	398,000	29,070	7.3
Rotterdam	552,000	32,323	5.9
NEW ZEALAND: (March 31, 1926)			
Auckland	193,000	14,655	7.6
Christchurch	118,000	10,055	8.5
Wellington	122,000	14,656	12.0
NORWAY: (June 30, 1925)			
Oslo	254,000	39,682	15.6
POLAND:			
Warsaw	960,000	36,314	3.8
ROUMANIA:			
Bucharest*	365,000	11,730	3.2
RUSSIA:			
Kazan	170,000	1,566	0.9
Kharkov	388,000	4,800	1.2
Leningrad	1,511,000	38,418	2.5
Moscow	1,913,000	48,378	2.5
Odessa	390,000	2,598	0.7
SPAIN:			
Barcelona	710,000	18,596	2.6
Madrid	751,000	17,857	2.4
Seville	206,000	1,814	0.9
Valencia	251,000	3,262	1.3
SWEDEN:			
Goteborg	231,000	28,993	12.5
Malmo	116,000	14,893	12.8
Stockholm (excluding Bromma and Brännkyrka)	381,000	107,173	28.1
SWITZERLAND:			
Basel	138,000	14,512	10.5
Berne	108,000	12,222	11.3
Geneva	126,000	15,497	12.3
Zurich	207,000	26,524	12.8
UNITED STATES:**			
New York	5,896,000	1,415,108	24.0
Chicago	3,059,000	790,711	25.8
Los Angeles	1,150,000	280,754	24.4
Total of the 8 cities with over 1,000,000 population	17,419,000	3,840,327	22.0
San Francisco	695,000	215,464	31.0
Cincinnati	657,000	140,547	21.4
Milwaukee	605,000	120,924	20.0
Total of the 10 cities with 500,000–1,000,000 population	6,546,000	1,206,930	18.4
Washington	482,000	129,405	26.8
Minneapolis	457,000	115,833	25.3
Portland, Ore	341,000	84,432	24.8
Omaha	223,000	61,601	27.7
Total of the 30 cities with 200,000–500,000 population	8,675,000	1,701,905	19.6
Total of the 48 cities with over 200,000 population	32,640,000	6,749,162	20.7

* Partly estimated.

** There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups and the development of certain representative cities within each of such groups.

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A Journal of Progress in the Telephone, Telegraph and Radio Art

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Portrait of Heinrich Hertz

Pioneers of Electrical Communication

HEINRICH RUDOLF HERTZ—V

By ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

THE work of the earliest pioneers of electrical communication culminated in the spring of 1886, when Heinrich Rudolf Hertz demonstrated at Karlsruhe the wave character of electrical transmission through space and through wires. With self-detachment as worthy of remembrance as the discovery itself, he hastened to suggest that he had but verified what others had foretold, that some phenomena exhibiting electric waves had been observed earlier by von Bezold, and that the theory upon which the Karlsruhe results were based was derived from Faraday, Maxwell and von Helmholtz. Physicists throughout the world at once recognised, however, that where others had hesitated Hertz had gone forward with firm steps, that where others had surmised he had measured, and that where others had comprehended in part he had established the theory of a universal group of converging facts. To all experimenters his announcement brought encouragement and inspiration. It was the old injunction, *Fiat lux*.

Heinrich Rudolf Hertz was born at Hamburg on February 22, 1857. He was the eldest son of the advocate, Gustav Hertz. On his father's side he was of Jewish origin. His mother, whose maiden name was Elizabeth Pfefferkorn, was of Frankfort-on-Main where her father was a doctor of medicine, descended from a family that for generations had been Lutheran preachers in south Germany. The Hertz family had long resided as merchants in Hamburg. The grandfather of Heinrich was successful in that business and became a townsman of considerable local importance. This ancestor, as a pastime, studied natural science, and made for himself a small laboratory, the apparatus from which came into the hands of Heinrich as a boy. There is still treasured by Frau Professor Hertz at Bonn a chemical balance that belonged to that precious collection.

The father of Heinrich practised at Hamburg, Lubeck and Bremen. He was selected from the jurists to be Oberlandesgerichtsrat and afterwards to be a Senator of Hamburg. For him also natural science had attractions, but his principal study was language. Even when he attained the age of eighty-six and his eyes were no longer able to discern the text, he employed a scholar to read to him from the classics. This delight in language was transmitted to his son. Heinrich was an eloquent master of his own tongue; he was familiar with English and French, he knew enough Italian to read Dante with pleasure, and he retained intimate knowledge of the humanities. It is said that, as a youth in Hamburg, he purchased from a bookstall an Arabian grammar, he decided to master it, and he engaged a teacher—one Redlob—to instruct him in Arabic.

Thus the great physicist was born of dual race, into a family that had risen in the scale, and that by nature was intent upon intellectual studies. While he was a lad, there moved over Europe the trade-winds of technical education with a pressure centre in Germany. Under this influence the relative prospects of "techniker" and "klassiker" were freely discussed, and choice had to be made between a commercial and a professional career. It is remarkable that, notwithstanding these circumstances, the education of Hertz was throughout unorthodox, and to some extent self chosen. Rudiments were acquired by him at the private Bürgerschule of Dr. Lange, in Hamburg, where boys were prepared for city avocations as practical townsmen, without Greek or Latin. Hertz was quick to discern that his friends at other schools derived advantage from the classics, and he persuaded his father to arrange for him to have special lessons in those subjects. Accordingly, he left the Bürgerschule at fifteen, and had a private tutor every day for one hour. During the remainder of each day, he studied by himself, and it was at this period that he fitted out a room at home with bench and lathe to make simple apparatus for experiments in physics and chemistry.

At seventeen he entered the Gelehrtenschule of the Johanneums at Hamburg, where he completed his classical studies. He left there at Easter, 1875, with the diploma. It was at this stage that he realised the distinction between engineering and pure science. He doubted whether he was adapted for scientific work; he was conscious of the pleasure to be derived from problems of mechanical construction, and he decided to study for a "practical year" with a firm of engineers at Frankfort-on-Main. At nineteen he proceeded to the Technical High School of Dresden, where he remained for six months. Then followed a year of military service with the Eisenbahn-Bataillon, of Berlin. Once more he had to choose between the same two careers, but at last—in November, 1877—he realised that only in natural science could he find the freedom, the scope and the field of discovery for which he longed. He went to Munich, nominally for engineering studies, "surveying, building construction, builders' materials, and such like"; actually, however, after consulting his parents and obtaining their approval, he diverted his course towards mathematical and experimental physics—the territory he was destined to make his own. That winter was spent in seclusion for the study of mathematics, mechanics, and physical laboratory work. A year later he was transferred to Berlin to acquire the stride of the giants—von Helmholtz and Kirchhoff.

His first independent research in physics had its origin in a question set as a prize subject by the philosophical faculty of the university of Berlin:

> " If electricity moves with inertia in bodies, then this must, under certain circumstances, manifest itself in the magnitude of the extra-current—i.e., in the secondary current which is produced when an electric current starts or stops. Experiments on the magnitude of the extra-current have to be made such that a conclusion can be drawn from them concerning inertia of the electricity in motion."

It will be recalled that a somewhat similar question had presented itself to Maxwell. In the endeavour to solve the riddle, Hertz carried out at the university a series of investigations, using some of the apparatus from his home. He wrote the account of his results during a period of military service, at Freiburg, and he gained the prize—a gold medal. The research in itself was of little importance, for the results were negative in character. Its value was in revealing the philosopher and in giving him a bent and encouragement upon the threshold of his career.

The speed at which he reasoned and worked on this investigation, on his subsequent researches on induction in rotating spheres, and on the distribution of electricity over the surface of moving conductors, was astonishing. It can only be accounted for by the zeal and delight with which he entered into the game of scientific discovery. His merit was at once recognised by the Berlin Philosophical Faculty. The university of Berlin conferred upon him the distinction of doctor and the rare award, *magna cum laude*.

His paper on induction in rotating spheres—the subject of his inaugural dissertation when taking his degree—reveals how early he became acquainted with the theorems of Maxwell, for it bears the date of March 15, 1880.

In October, 1880, Hertz was selected by von Helmholtz as demonstrator in physics. This association lasted until Easter, 1883. There is a legend that when von Helmholtz, at this period was asked to explain any obscure points in electrical theory, he would advise his interrogators to consult his assistant, adding that " Dr. Hertz has already arrived at the answers to these questions." Two centuries earlier a relationship somewhat of like kind existed between Galileo and Torricelli.

From Berlin, Hertz departed in 1883 to take up the appointment of lecturer in theoretical physics at the university of Kiel. There he devoted himself partly to the solution of theoretical problems, and partly to the clearing up of doubtful questions by experiment. What the future held in store for him was indicated by definite foreshadowings. On January 27, 1884, he wrote in his diary: " Thought about electromagnetic rays. Reflected on the electromagnetic theory of light"; and in May of that year there are the entries: " Hard at Maxwellian electromagnetics in the evening. Nothing but electromagnetics. Hit upon the solution of the electromagnetic problem this morning."

His colleagues at Kiel recognised his qualities. They expected that his skill in experimental demonstration would lead him to things of importance. In two respects he quickly justified their conjectures. At Easter, 1885, he became professor in ordinary of experimental physics at the Technische Hochschule at Karlsruhe; and in 1886, at the age of twenty-nine, he married Elizabeth Doll, the daughter of Dr. Doll who was teacher of surveying at Karlsruhe University. The home of Hertz became a happy centre of university life. The laboratory at the Hochschule provided him with the means of materialising his ideas in electromagnetics.

In the spring of 1886, he found amongst the apparatus stored in the small but well equipped preparation room at Karlsruhe, "a pair of so-called Riess or Knochenhauer spirals," flat coils insulated with sealing wax (Figure 1); and he observed that the discharge of even a small Leyden jar through one of these sufficed to cause a spark to pass across a short air-gap between the ends of the other. It was the smallness of the jar needed for this purpose that first attracted his attention. Then he observed that, in a neighbouring conductor, side-sparks were produced. With a special form of sparking device he investigated the matter, and he discovered along this neighbouring conductor a neutral point. He thus recognised that he was dealing with oscillatory discharges, and he concluded that the series of oscillations in the conductor was regular.

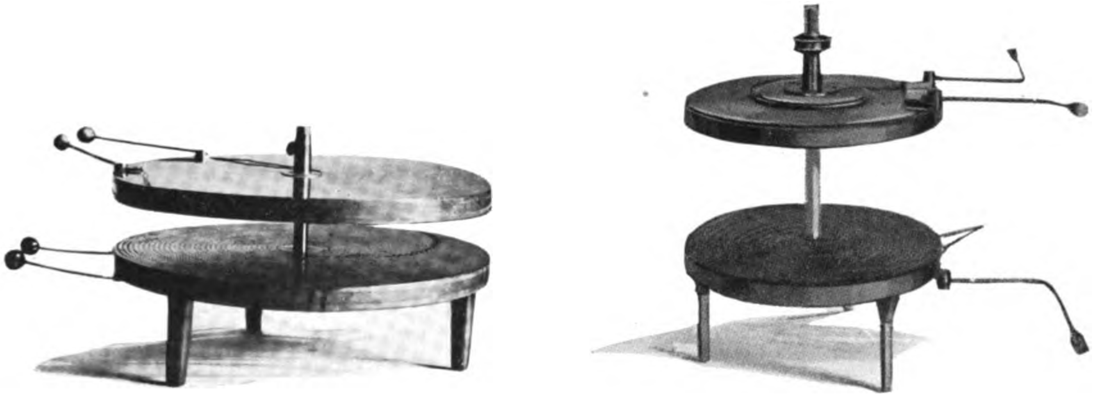


Figure 1—The Knochenhauer Spirals Used by Hertz at Karlsruhe

By the courtesy of the administrators of the Deutsches Museum of Munich, it is possible here to illustrate some of the original apparatus used by Hertz in those early experiments. The collection was acquired partly from Frau Elizabeth Professor Hertz, and partly from the Technische Hochschule of Karlsruhe. To realise its significance, it is necessary to consider where the work of Hertz enters the pages of electrical history. It was pointed out by Oliver Heaviside, in the "Philosophical Magazine" of March, 1877, that the oscillatory nature of a condenser discharge in association with self-induction was first discovered by Joseph Henry, in 1842, and that this work had been somewhat overshadowed by the discoveries made by Faraday. The theory of the reaction between a condenser and coil was given by Sir William Thomson—afterwards Lord Kelvin—in the "Philosophical Magazine" of June, 1853. The effect of self-induction in association with capacity in a telegraph line was first considered by Kirchhoff, in 1857, on the basis of the electrodynamic theory propounded by William Weber. Von Helmholtz dealt with the problem of the oscillations of a Leyden jar in 1847. It was worked at by Fedderson in 1858, and in the years 1861–1862 he demonstrated the phenomenon with revolving mirrors. Fedderson's original apparatus for this purpose is at Munich; it includes the negative he obtained of the light-band corresponding to the fluctuations of illumination at a frequency in agreement with Kelvin's formula connecting periodic time with self-induction and capacity. In 1864, Maxwell predicted that electromagnetic waves, in free space, would have the velocity of light. Upon this basis, the oscillations observed for example in the particular cases examined by Fedderson would have corresponded to wave-lengths of about 30 metres—lengths so great in comparison with the dimensions of the laboratories, that the wave character of the propagation in free space escaped notice by physicists preceding Hertz.

Next in order of time came the results of W. von Bezold. These were described in the "Berichte der Bayrischen Akad. d. Wissensch," in 1870 and were summed up by von Bezold himself as follows:

1. If, after springing across a spark-gap, an electric discharge has before it two paths to earth, one short and the other long and separated by a test-plate, the discharge current splits up, so long as the sparking distance is small. But when the sparking distance is larger the electricity rushes only along the shorter path, carrying with it, out of the other branch, electricity of the same sign.
2. If a series of electric waves is sent along a wire which is insulated at the end, the waves are reflected at the end, and the phenomena that accompany this process in the case of alternating discharges appear to be caused by interference between the advancing and reflected waves.
3. An electric discharge traverses wires of equal lengths in equal times, whatever may be the material of which these wires consist.

The early experiments of Hertz were carried out without knowledge of what had been accomplished by von Bezold. When the attention of Hertz was drawn to those results he paid a graceful tribute to them, and ultimately in his treatise upon electric waves he reproduced von Bezold's paper in a place of honour as an early chapter.

Hertz knew that the time of oscillation of small quantities of electricity in a circuit such as he was using is determined by an equation involving the resistance, self-inductance, and capacity of the circuit, including the spark-gap, and he proceeded to vary these cardinal factors to obtain quantitative results. He quickly realised that, by appropriate adjustment, a condition of "harmony," i.e., resonance, could be brought about between oscillating conductors and neighbouring circuits. In Figure 2, the upper part illustrates the method of operating the Knochenhauer spirals, where as was usual before Hertz, a Leyden jar is discharged through a circuit with no pretence to resonance. To increase the frequency, Hertz sought to reduce the capacity; he therefore eliminated the Leyden jar, as indicated in the lower part of Figure 2. By removing the Leyden jar, the two circuits became automatically resonant with one another. The

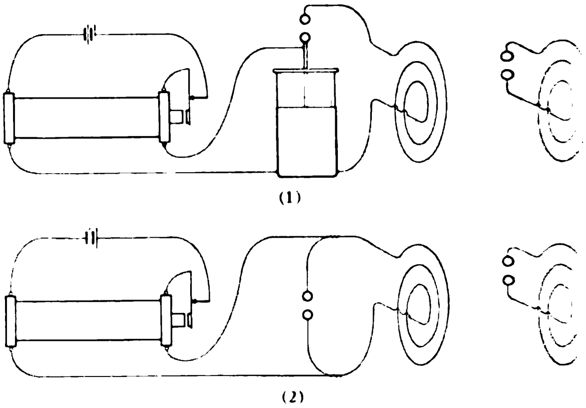


Figure 2—Arrangement of Knochenhauer Spirals

(1) With Leyden jar charged by induction coil

(2) Without Leyden jar, so as to obtain higher frequency by reduction of capacity

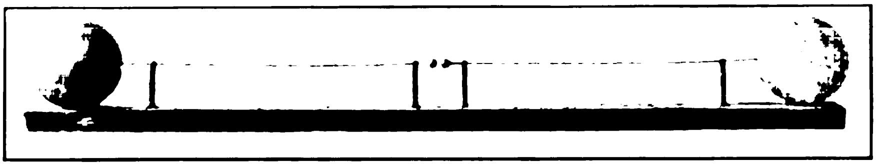


Figure 3—The First Oscillator of Hertz. Two copper wires, each 1 metre in length, supported on rods of sealing wax. The large spheres are of sheet zinc, and are 30 centimetres in diameter. Base 200 x 7.5 centimetres

primary circuit in this second arrangement was energised directly from the induction coil. By this means he produced electric waves. But he was not only concerned with the production of waves. He was intent upon investigating the nature of the "polarisation," if any, that the theories of Faraday and of Maxwell require in the medium between the generating and resonant circuits. At his hands, therefore, the dielectric received special attention.

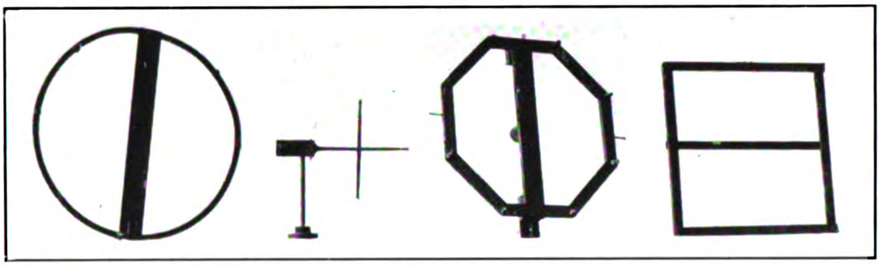


Figure 4—Four Resonators Used by Hertz. Dimensions, left to right, 70, 35, 67, 60 centimetres

The next development was to replace the generating spiral by a straight conductor, Figure 3, containing a central spark-gap. To adjust the capacity, the outer ends of the rods forming the conductor could be fitted with metal spheres or plates. This apparatus, when connected to an induction coil as in Figure 2, became the Hertz oscillator. The original apparatus had a frequency of about a hundred million oscillations a second. He found that the receiver also might be a straight conductor of similar construction, but he generally preferred a resonator of circular, square, or octagonal form, with a spark-gap, Figure 4. The gap could be adjusted by a micrometer. Care was taken that the oscillator and the corresponding resonators should be in "tune" with one another. To get rid of spurious sparks resulting from electrostatic induction he occasionally interposed a wet thread between the electrodes of his spark-micrometer.

In most cases Hertz used as a detector the spark directly observed at the gap in a resonator, and measured by the spark-micrometer. Occasionally he employed a hot-wire galvanometer, and in some circumstances a suspended tube of gilt paper, Figure 5. By such means, he surveyed space and determined the positions of nodes, and anti-nodes, and the length and frequency of waves.

His investigations then extended to the study of reflection, refraction, and polarisation, in the optical sense, of electromagnetic waves. For this purpose the oscillator and the resonator were placed respectively at the principal foci of two parabolic mirrors of sheet zinc, each 2 metres in height, illustrated in Figures 6 and 7. A wave-length of about 50 centimetres was used. The receiver consisted of two thin brass wires, each about 52 centimetres in length, connected to a spark-gap outside the parabolic mirror. He obtained results up to a distance of about 16 metres; and he found that the waves could penetrate a wooden door, but not a zinc screen. The ordinary laws of reflection were proved by him to hold for electric waves. To examine the phenomenon of refraction he employed a prism of pitch weighing about 800 kilogrammes. He stated that in passing from air into a solid transparent medium the action exhibits a refraction like that of light, but that it is more strongly refracted than is visible light.

In the earlier experiments his induction coil was 52 centimetres in length and 20 centimetres

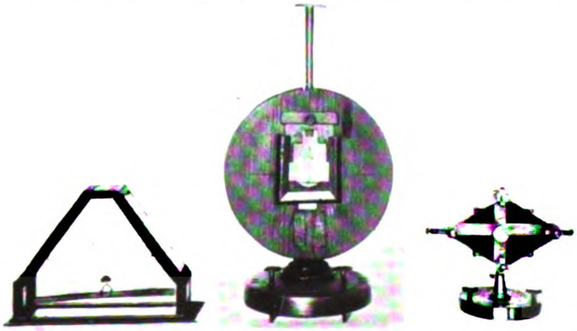


Figure 5—Detector (at left) Consisting of a Tube of Gilt Paper and Case 16 Centimetres in Height. Tangent Galvanometer, Height 40 Centimetres, Diameter of Disc 22 Centimetres. Hot-wire Galvanometer in Lozenge-shaped Case 17 Centimetres High, 18 Centimetres Wide

in diameter. It was operated by six large Bunsen cells, through a mercury interrupter, Figure 8. Later he preferred a smaller induction coil, having a maximum spark-length of 4.5 centimetres. It was operated by three accumulators. Sparks from 1 to 2 centimetres between the knobs of the primary conductor sufficed for many of his experiments. The spark-gap in the resonators was small—in some cases about 3 millimetres. With such apparatus he satisfied himself that the propagation is rectilinear. To demonstrate the phenomenon of polarisation, in the optical sense, he utilised his mirrors in a manner similar to that applied to the polariser and analyser of an optical polarisation apparatus. He made (Figure 7) an octagonal frame, 2 metres high, across which he stretched copper wires 1 millimetre in diameter, parallel to one another, 3 centimetres apart. It behaved as a tourmaline crystal behaves towards a plane-polarised beam of light.

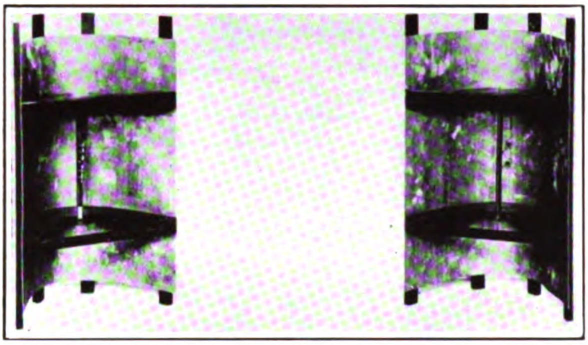


Figure 6—Parabolic Mirrors 2 Metres in Height. One contained an oscillator and the other a resonator. (See also Figure 7.)

Hertz soon confirmed the views of Heaviside and Poynting that the process whereby currents are induced in secondary circuits by such oscillations as he was employing, takes place for the most part in the surrounding dielectric, and that the interior of secondary conductors plays scarcely any part. As the action from the primary in his experiments traversed the air point-to-point to the secondary, propagation was there of necessity concerned with the dielectric. At high frequencies a metallic sheet, placed round the secondary, effectively screened that circuit. He then asked, to what extent may the thickness of the sheet be reduced? Such tinfoil as was available was thick enough to prevent penetration; so was gilt paper. Below the mere surface of the conductors, therefore, all was complete calm. He deduced that such electric waves scarcely penetrate further than does the light reflected from the surface of a conductor.

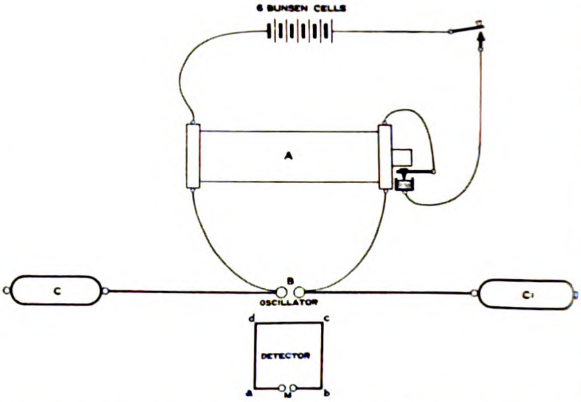


Figure 8—General Arrangement of Hertz Oscillator and Resonator

Near one of the end plates of his primary conductor he then placed a conducting plate and fastened to it a long straight wire. In his earlier experiments, he had already shown how the action of the primary oscillation could be conveyed to great distances by such a wire. He now demonstrated by suitable screening that all the effects are restricted to the surface and to the space outside such a wire, and that the interior knows nothing of the waves. He went so far as to try screening with glass-tubes chemically silvered, and at last, with this screen immeasurably thin, it was possible to penetrate the conducting barrier. The sparks at the detecting gap within appeared only when the film of silver was no longer opaque to light, and when it was certainly thinner than $\frac{1}{1000}$ millimetre. Like results were obtained by screening the primary. Care had to be taken, however, to avoid openings at the ends and elsewhere in the screens. It was in the course of these experiments that he constructed the apparatus for stationary electric waves, resembling an elongated squirrel-cage (Figure 7, No. 40070) 5 metres long and 30 centimetres in diameter. It was built up of twenty-four copper wires extended parallel to one another along the generating cylindrical surface, over seven rings of wire equally spaced. It was provided with a central wire, and he constructed a very small exploring resonator, with an adjustable spark-gap, for examining the distribution of nodes and anti-nodes within the cage. Thus he satisfied himself, and thus he propounded the paradox that

> Whereas all propagation of electrical disturbances takes place through non-conductors, conductors oppose this propagation with a resistance that in the case of rapid alternations is insuperable.

Then reverting to the idea of electrical "polarisation," he regarded the oscillations as being so rapid—he was dealing with about a hundred million a second—that the quantities of electricity displaced in insulators by such "polarisation" are of the same order of magnitude as those set in motion by conduction in metals. When iron wire replaced copper, he obtained similar results and thereby confirmed his supposition that with iron the magnetism cannot follow such exceedingly rapid oscillations. He expressed regret that he had no experimental data with regard to how the discharge of Leyden jars is affected by the presence of iron. Probably he conceived that such discharges, owing to the comparatively great capacity of the jars, would be of considerably lower frequency than discharges from his ordinary oscillator of very small capacity.

To increase the self-induction of the resonating circuits he introduced loose spirals, Figure 9. He also examined the effect of using wires of different metals, particularly of iron. Conductors such as those illustrated in Figure 7, No. 40069, were for modifying the capacity of his circuits. Occasionally he explored the circuits for nodes by spark-gap tests carried out by the aid of a small insulated metal sphere brought near to

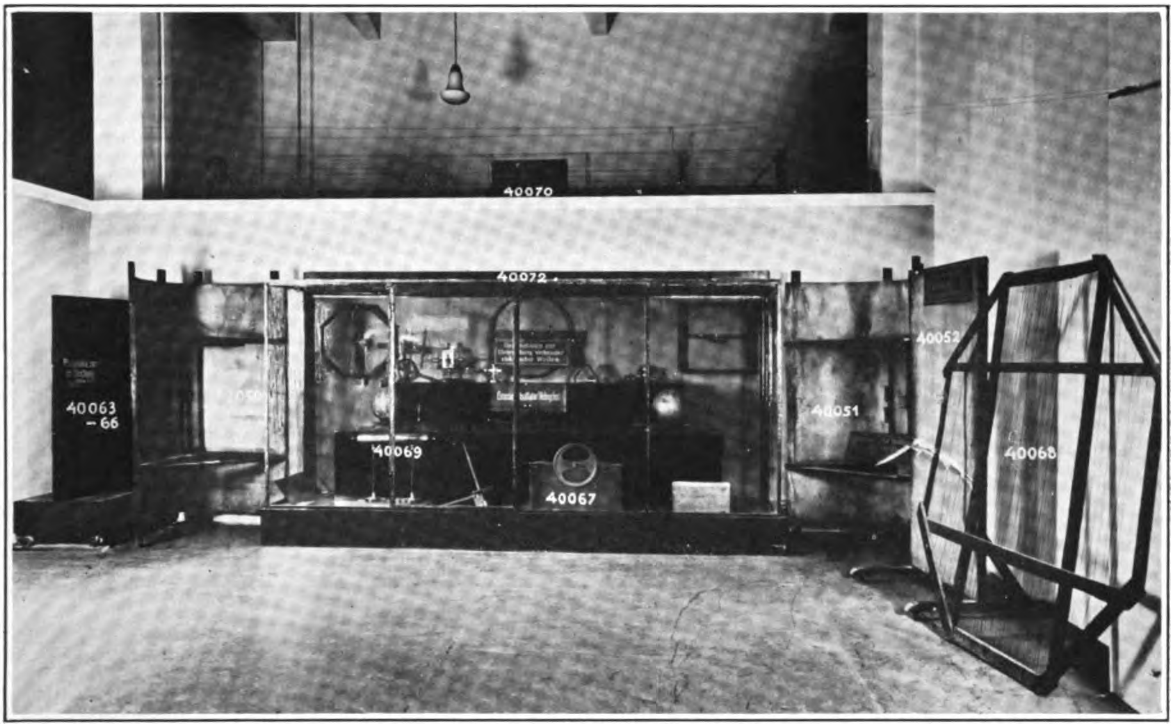


Figure 7—Collection of Hertz Apparatus at the Deutsches Museum, Munich. No. 40050, parabolic mirror with resonator. No. 40051, parabolic mirror with oscillator. No. 40052, plane mirror, 2 metres high and 1 metre wide, of sheet zinc. No 40063—66, pitch prism, height 1.59 metres, width 1.20 metres, weight 1200 kilogrammes, for refracting electro-magnetic waves. No. 40068, octagonal grating of wires on frame 2 metres high, made by Hertz for experiments on "polarisation." No. 40069, cylindrical conductor upon two glass supports, used for varying the capacity of circuits. No. 40070, "squirrel-cage" consisting of 24 copper wires, each 5 metres long, forming a cage about 30 centimetres in diameter for experiments on stationary electric waves. No. 40072, wooden trough, 21.5 centimetres wide and 45 centimetres in length, for experimenting with electric waves in liquids

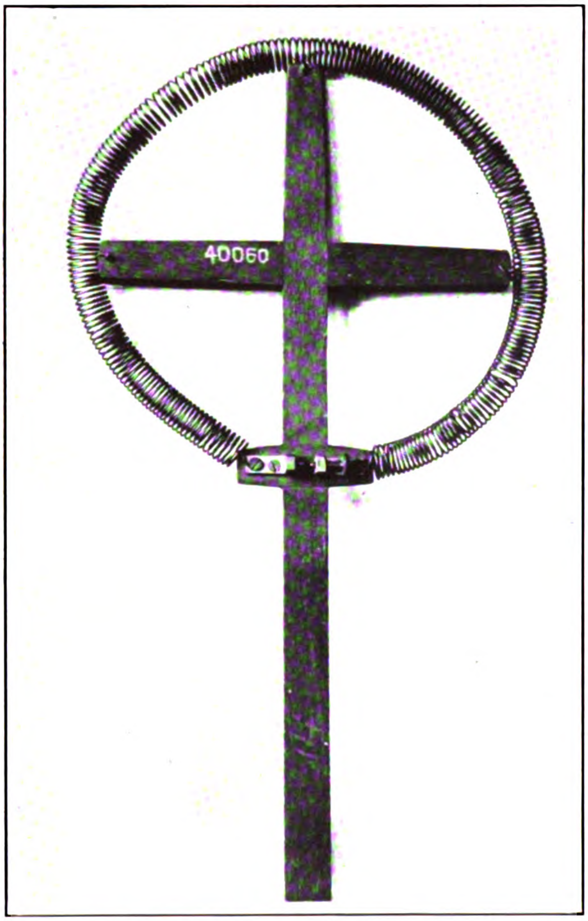


Figure 9—Circular Form of Resonator, 21 centimetres diameter, of brass wire wound into a spiral to increase self-induction for long waves. The micrometer spark-gap is here illustrated

the conductors at various points. It was by this means that he first became aware that "overtones" were present, and that irregular effects were superposed upon regular effects.

From the tangled threads of growing knowledge concerning these irregular effects he proceeded to weave a new research. He observed that the sparks at the gaps of the exploring resonators were influenced by light from any neighbouring sparks—for example, by light from the originating spark at the induction coil. He was in this manner led to discover the influence of ultra-violet light upon electric discharges. The original apparatus employed by Hertz at Karlsruhe to demonstrate this effect is illustrated in Figure 10. A vacuum is first formed in the receiver by an air-pump, and the spark-gap is adjusted so as to be somewhat too long to allow the discharge, with ordinary illumination, to take place. Ultra-violet light, from another spark or from some other source, is then allowed to fall upon the gap, ionization consequently occurs, and the spark passes. Screening of the spark-gap from ultra-violet light consequently diminishes the maximum spark-length in a resonator corresponding to any given arrangement of the resonator. These results were published by him in June, 1887.

In the summer of 1887, Hertz studied the influence that he thought might be exerted by dielectrics upon electromagnetic waves. His usual mode of investigation was to examine the effect of the presence or absence of a block of insulating material upon the position of the neutral point in one of his radiators. The form of his original apparatus for this purpose is illustrated in Figure 11. He subsequently regarded this work as fruitless—his efforts being frustrated by the occurrence of subsidiary sparks. Ultimately he followed a new line, and was rewarded by finding that the distance to which he could detect electromagnetic waves might be extended. Distance in fact was not determined by the Newtonian law of inverse squares. He pressed on, and succeeded in transmitting up to the then enormous distance of 12 metres. His experiments on the reflection of waves were completed in March, 1888. The summer of that year was given to the study of the propagation of waves by means of wires, and in September, 1889, he delivered at Heidel-

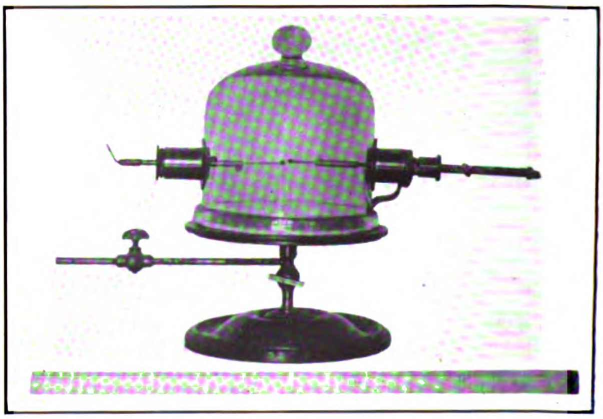


Figure 10—Original Apparatus Used by Hertz at Karlsruhe, to illustrate the effect of ultra-violet light on electric discharge

berg his famous lecture on the relations between light and electricity.

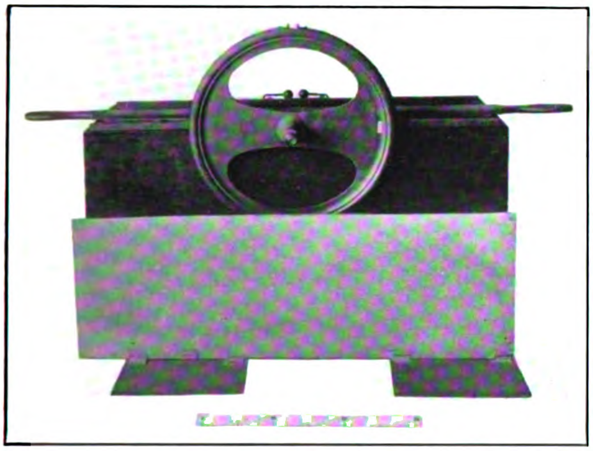


Figure 11—Wooden Box Containing a Block of Paraffine Wax, 70 x 32 x 18 Centimetres. Resting on the box are rectangular brass plates forming an oscillator, the spark-gap of which is seen through the aperture. The oscillator was raised or lowered onto the block to observe the effect, if any, of the presence of the dielectric (wax). The circular apparatus carries a wire, forming a resonator, the small spark-gap of which is seen at the top. In front is a metal sheet, used by Hertz as a plate of a condenser

To obtain an idea of the conditions under which the earliest experiments in Hertzian wave transmission were carried out, a visit was paid to Karlsruhe (Baden). By the kindness of Professor Gaede, who now (1927) occupies the professorship held by Hertz, the Hertzian apparatus was reassembled in the lecture theatre of the Physikalisches Institut of the Technische Hochschule, in the positions where Hertz originally arranged them, and the photograph reproduced in Figure 12 was obtained to illustrate the present account of the experiments. From left to right, there is first seen upon a small table some bichromate cells, and the original induction coil used by Hertz. Then appears the parabolic mirror of sheet zinc containing the *Sender*, or oscillator. Next to this is the pitch prism, and then the second mirror containing the *Empfänger*, or receiver. These mirrors are exact duplicates of the originals, and were made by the Institutsmechaniker, Amann, who constructed the originals for Hertz. The originals are at Munich (Figures 6 and 7). To the right of the *Empfänger* in Figure 12 is the wire cage for experiments on skin-effect, and on the extreme right is the plane mirror of sheet zinc. In the foreground on the right is a corner of the lecture table. The preparation room is approached by a door at the back of the lecture table. An inscription on the wall of this lecture theatre, not visible in Figure 12, reads:

> "In diesem Saale stellte Heinrich Hertz seine ersten Versuche mit Elektrischen Wellen an."

It was also in 1889 that Hertz was appointed to succeed Clausius and Ketteler as ordinary professor of physics at the university of Bonn. At Bonn he had as colleagues Breisig, Lenard, and his own brother-in-law, Carl Pulfrich. He there set before himself the task of building up a simple electromagnetic theory upon the principles of Maxwell, as confirmed by his own experiments. He also directed his attention to the discharge of electricity in rarefied gases; an appropriate research, for Bonn had already to its credit the achievements of Hittorf, Geissler, Kayser, Pluecker and others, and a laboratory scintillating with original apparatus—the weapons of their victories in this field. Pluecker in 1859 had studied the fluorescent effect that cathode rays produce upon the glass walls of a discharge tube; Hittorf, Goldstein, Puluj and Crookes had continued the investigation. Hertz gave new direction to scientific thought. He experimented with thin plates of metal fixed inside a discharge tube, and he was rewarded by the discovery that cathode rays can be made to pass through metals. Then his colleague Professor Philipp Lenard conceived the idea of inserting such a metal plate in the glass wall of the tube, as a "window" through which the cathode rays, imprisoned within the glass, might escape. They did. The rays stole out into the open and assumed disguise as "Lenard rays." Lenard is said to have given one of these tubes to Roentgen of Würzburg. In the autumn of 1895, Roentgen was experimenting with invisible light—from a discharge tube enclosed in black paper. He discerned the penetrative power of rays that proceeded from the bombarded regions, i.e., from the regions of impact of the cathode rays against the interior surfaces of the discharge tube in which they were generated. So nearly did Hertz and Lenard find the little more that was to be so much.

The sequence of discoveries by Pluecker, Goldstein, Hertz, Lenard and Roentgen must remain an example of the ease with which observers can hit or miss what may be just behind the surface of achievement in natural science.

Most of the discoveries with which the name of Hertz is associated were made known originally in "Annalen der Physik und Chemie." These writings were collected by him. After adding some explanatory notes, and a dedication to von Helmholtz, he published them in 1891 as a treatise, with the title "Untersuchungen ueber die Ausbreitung der elektrischen Kraft." This book was admirably translated into English by Professor D. E. Jones, and a preface to the English edition was written by Lord Kelvin. The English title of it was "Electric Waves, being researches on the propagation of electric action with finite velocity through space." Later there was issued "Miscellaneous Papers" with an introduction by Professor Philipp Lenard. These papers included an account of the earlier investigations, and brought together writings otherwise difficult of access. The work was translated into English by Professor D. E. Jones and Professor G. A. Schott. To complete the collection there was also issued Hertz's "Principles of Mechanics." The whole series was edited by Professor Lenard. Additional notes of a biographical character are to be found in the address given in 1894 by Professor Franz Richarz to members of the University of Bonn, and in some brief writings of Dr. F. Breisig. Useful particulars concerning the relics of apparatus are contained in a short article by Dr. Franz Fuchs in "Der Radio-Amateur" for April, 1926.

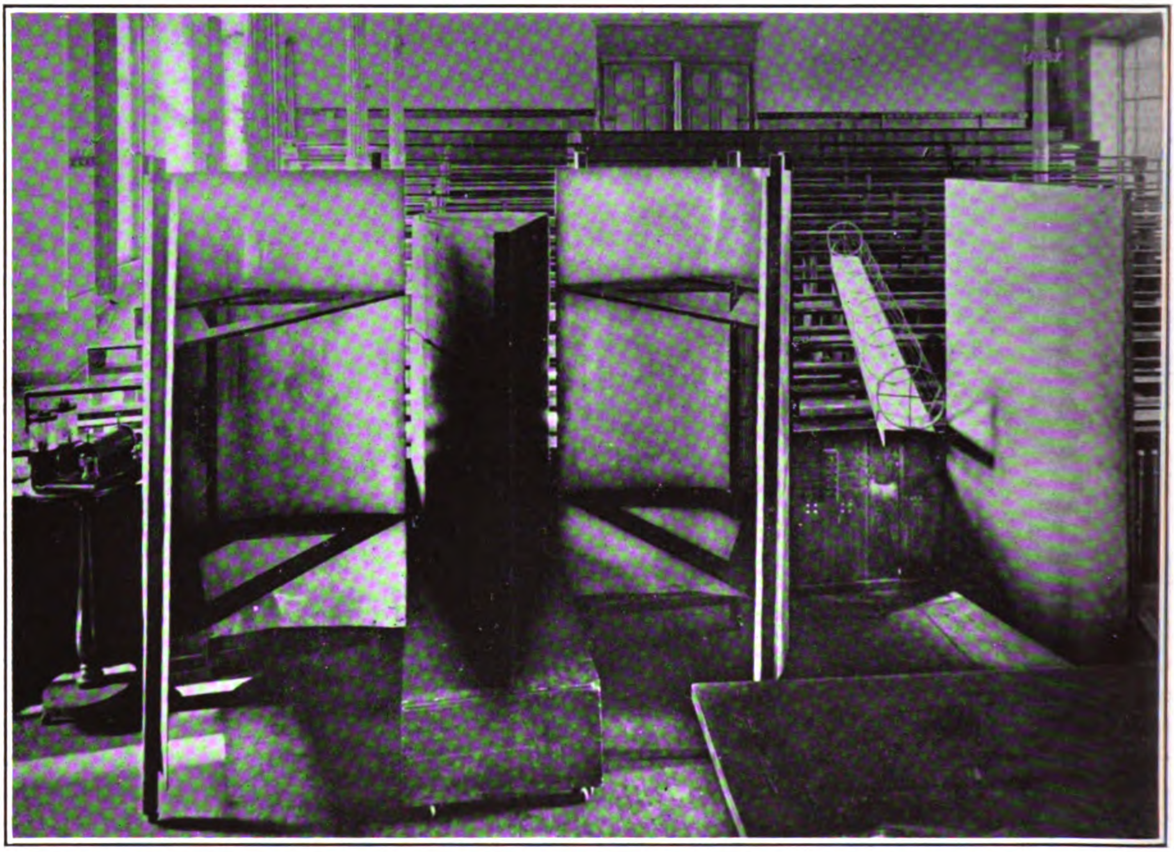


Figure 12—The Lecture Room at the Physikalisches Institut at Karlsruhe, with apparatus as arranged in the experiments by Hertz in the years 1885 to 1889, that led to his discovery of Hertzian waves

The closer the early papers are studied, the greater becomes the amazement that Hertz who had applied himself seriously to mathematical physics for rather less than two and one-half years should have obtained so quickly such a grasp of the most intricate part of the subject. He himself confessed to the inestimable value of the inspiration that von Helmholtz imparted to him and to other pupils, to the preeminent fitness that von Helmholtz possessed for guiding them in original research, and to the value of this personal influence, that led them to see things as part of all creation instead of as separate entities. This guidance by von Helmholtz was free to all who came under the care of that illustrious and beneficent philosopher—it could direct but could not evolve such genius as that of Hertz. The truth is that Hertz possessed remarkable powers of sweeping away from elaborate theories everything but the part needed to assist in attaining his object. This hint he has left us. The remainder of the secret was bequeathed by him as a theme for research students for all times.

In his philosophy, Hertz was in all respects a Newtonian. For him, the group constituting electricity, magnetism, and light, belonged to mechanics. The difficulty was, as he confessed, that the mechanics of that group had not been completely disclosed to human understanding. In his earliest work (1886–1887) he had not perceived that the laws of electricity applicable to the steady state differ from those of electricity in motion. When he realised the distinction, he immediately advanced. He first ascertained that the oscillations with which he had to deal were characterised by variety and regularity. Then, out of confusion came order; but it was not the old order, for the amplitudes of these regular oscillations decreased more slowly than inversely as the square of the distance from the source. Next, the distances traversed by the electric waves surprised him, even with his crude means of detecting them. Moreover, the waves had finite velocity. He then knew that the immemorial doctrine of "action-at-a-distance" must die, and that the Faraday-Maxwell theory, which had not yet been fully appreciated in Germany, must supercede it.

Hertz saw that Maxwell's theory involved three assumptions, all relating to the dielectric medium through which the electric and magnetic forces are exerted. In effect, he said, consider the space between the two plates of a simple condenser. Apply a battery suddenly to the terminals. There is an initial current through the dielectric—Maxwell's displacement current—but not a continuous steady current. The electric stress has produced in the condenser an electric strain, a strain not exceeding the limits of the tenacity of the dielectric. Maxwell had assumed:

(1) That such changes of electric stress correspond to the same electro-magnetic forces as do the steady currents equivalent to them.

(2) That forces, electromagnetic as well as electrostatic, are able to produce dielectric stresses.

(3) That air and empty space behave like all other dielectrics.

Hertz then deduced, from Maxwell's equations, that if (1) and (2) are correct, waves of the kind expected by Maxwell could be propagated in any given dielectric with finite velocity, not necessarily the velocity of light. Hence, if a wave could be shown to be propagated at finite velocity in air, (1) and (2) might be proved to hold. In this demonstration, after some preliminary failures, he succeeded. Then he investigated stationary waves along straight wires, their nodes and anti-nodes, their wavelengths, their phases and their phase-differences, their reflections and their mutual interferences. At about this time he became for once disheartened—the rate of propagation seemed to be infinite, and the phase of the interference seemed different at different distances. Was Maxwell's theory then false? He left the matter alone for a few weeks, and then tried again. His genius had left him desolate. He was moreover disturbed because the account of his research was marred by an error of calculation—to which Poincaré had drawn attention. Further, could it be that electricity possesses inertia, after all?

Discouragement did not restrain him from research. Freeing himself from preconceived notions, he repeated his experiments and found that the set of wave interferences which he had observed could not be harmonised upon the assumption of infinite velocity. He now thought that velocity in air must be finite, and greater than that in a wire. Then followed misgivings concerning the possible effect of the neighbouring walls, the iron stove, and other obstructions. It is said that at this time he remarked upon the benefits that might result if science had available an enclosed space comparable with that of Cologne Cathedral. During this period he discovered that for long waves the velocity was greater in air than in wires, but for short waves he found practical equality. He declared the result to be so surprising that he could not accept it as certain. His doubt arose once more from the environment, for he reasoned, if long waves cannot be developed, they cannot be observed. He knew that the velocity of the wave in any case depended upon the reciprocal of the square-root of the product of specific inductive capacity and permeability. He also knew that, at such high frequencies as he was using, only the surface layers of conductors come into play. These facts, however, did not completely satisfy him. Again he appealed to experiment. In the autumn of 1888, while investigating waves in the narrow interspace between wires, by means of small detectors, he found distinct nodes at or near the ends of the wires, even when the detectors were very small. This brought him on to the track of very short electric waves and enabled him to repeat, with waves only 30 centimetres in length, all his earlier experiments. He found that in wires such waves travel with very nearly the same velocity as in air. But he was still dissatisfied, for his view was that an experiment carried out under proper conditions would prove not only that the velocity in air is finite, but that the velocity in air and in wires is equal. Also he was influenced by the teaching of von Helmholtz that a distinction must be maintained between the electromagnetic and the electrostatic forms of force, and that until the contrary is proved they must be assigned two different velocities. He sought to establish the true relationship between the two forms by observing the mechanical forces exerted by the waves upon ring-shaped conductors.

It is well to remember that these famous experiments were carried out with apparatus simple and inexpensive. In the physics departments at Karlsruhe and at Bonn were indeed precious relics of the preceding age, but Hertz converted to his purpose the ordinary contrivances in metal, wood, glass, silk, tin-foil and sealing wax that might have been found in any university laboratory of his time. What further was needed he made, after the manner of the pioneers, with his own hands, out of bits of wood and wire and sheet-zinc, so that all was infinitely adjustable.

The error that crept into the calculations relating to his work, and that caused him such annoyance, was of a subtle kind. He was determining the time of oscillation of his usual form of oscillating system, consisting of a straight conductor with a sphere at each end, as in Figure 3. The expression for this time involves the square-root of the capacity of one of the equal spheres. When the spheres are far apart, the charge on each is the product of this capacity and the potential difference between the sphere and the earth. In his calculation he took the potential difference to be that between the two spheres. This was equivalent to calculating the capacity of one of the spheres to be 15 instead of 15/2. The effect was that he estimated the required time of oscillation as 1.77 instead of 1.26 hundred millionths of a second. That so great a philosopher should have been thrown into despondency concerning a matter of only 5.1 thousand millionths of a second is probably unique in the history of human effort. Even after Poincaré had placed the fine point of his cambric needle upon this error, Hertz was not content, for in 1891 his own comment was:

> "Abgeschen davon, dass in der Rechnung der eben erwähnte Fehler zu corrigiren wäre, ist auf die Dämpfung durch Strahlung keine Rücksicht genommen, an welche ich bei Abfassung dieser Abhandlung noch nicht dachte."

In other words, he accused himself, in addition, of having neglected the chance losses by radiation. These radiation losses have since received the attention of profound mathematicians including Larmor, Lorentz, Planck and Schott, and the outstanding fact remains that, as Hertz realised, a rigorous method of evaluating losses by radiation has yet to be found. To derive from the life and works of Hertz the greatest help and encouragement, the investigator must realise how completely he combined those qualities of a philosopher that make an observer, a logician, and a mathematician.

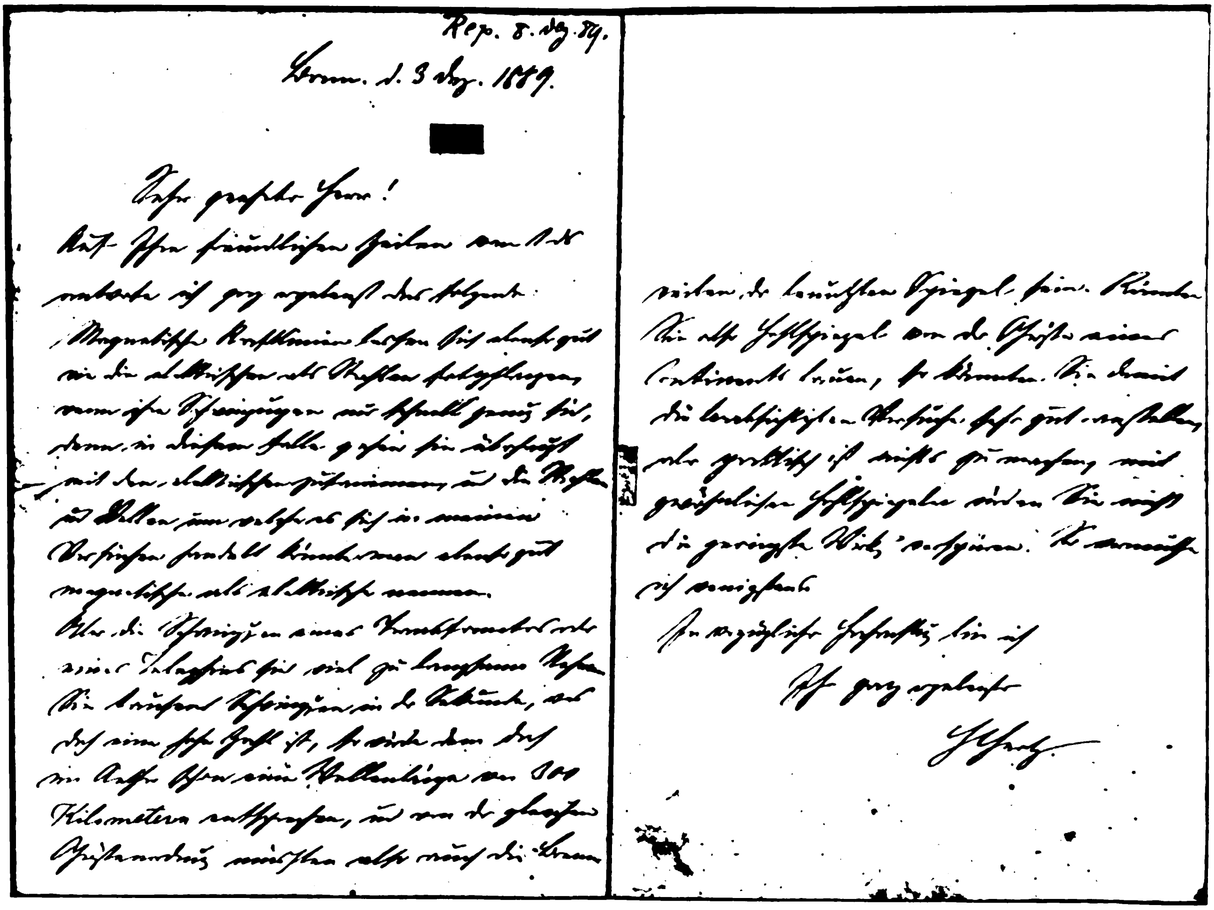
Although he derived his primary inspiration from the mathematics of von Helmholtz and

Clerk Maxwell, he was able at will to free himself almost completely from the allurements and restrictions of symbolism. By direct experiment he proved that the propagation of electric waves through space is an affair of time as well as an affair of distance—a point to point process through a continuous entity that can undulate. He thus disposed of the theory of electrical action-at-a-distance, i.e., the theory that electrical actions, like thought itself, can spring instantly across space. Following Faraday and Maxwell, he taught that electrical and magnetic forces can disentangle themselves from inert bodies, and that they can continue to exist as wave conditions or changes in the state of the medium. Finally, he confirmed by experiment the close correspondence between electric and magnetic forces and light.

Between the teachings of the English and German schools of thought he was in a position of some delicacy. He saw that with the acceptance of Maxwell's idea, the physical basis of von Helmholtz's theory must disappear—for action-at-a-distance would become intolerable. He had therefore to go carefully through Maxwell's work step by step, stumbling as others had done "upon unwonted mathematical difficulties," and again as others had done abandoning hope of forming for himself an altogether consistent conception of Maxwell's ideas. "What, he asked at last, is Maxwell's theory? Maxwell's theory is Maxwell's system of equations." The recognition of this fact enabled him to be up and doing, and to follow further the injunction of Maxwell, to sweep the cobwebs off the sky.

His analysis began with scrutiny of the four theories that in his day held the field, relating to the attraction between two electrified bodies. Briefly, the first of these presupposed a kind of spiritual affinity. It recognised that the force exerted by the first body is intimately associated with the presence of the second body, thus resembling the attraction between two magnets. Here was primitive action-at-a-distance, naked and unashamed. It was consistent with Coulomb's law. It held for gravitation. With what happened in empty space it had no concern. For electricity this theory had to be abandoned. The second was also of a pseudo spiritual character. It too applied to the case of two bodies, but each body strove to attract in all directions with forces of definite magnitudes, even if no other bodies were present to respond. Space was filled with strivings that varied from consecutive point to consecutive point of a vague universe. Each body was at once the seat and the source of forces. Whether space was full or empty was immaterial. Hertz considered that Maxwell adopted some but not all of this second theory. The third was a development of the last. The attraction between the two separate bodies was not in this third theory determined solely by forces operating in accordance with the principle of action-at-a-distance. Space came into it. Space was no longer empty. The forces induced changes in the condition of space. These changes gave rise to new action-at-a-distance forces. Electricity and magnetism implied here the "polarisation" of each of the smallest parts of space matter, and this "polarisation" was brought about by the forces. The attraction between the two electrified bodies depended partly upon the influence of changes in the medium. Similarly, the energy was, in general, partly in the electrified bodies and partly in the medium. In the limiting case of this theory, the whole energy was in the medium, and there was no so-called "free" electricity; consequently in the limiting case the action-at-a-distance force vanished. Hertz saw that this limiting case led to Maxwell's theory, although the physical ideas were, in his view, not Maxwell's. The fourth theory transferred the action entirely to the agency of the medium. The changes in the medium—contemplated in the third theory—were present in the medium in the fourth theory, but in the fourth there were no action-at-a-distance forces to cause "polarisations." Yet "polarisations" were the only means of action present. They caused the movements of the attracted bodies. How the "polarisations" were formed was unknown—consideration of the physics of that matter was to be deferred. Thus, according to Hertz, did Maxwell view the physical universe, thus did Maxwell discard action-at-a-distance, and upon the foundation of this fourth theory did Maxwell build his System of Equations.

As a mathematician, Hertz possessed more than ordinary knowledge and skill; his mind



Rep. 8. Dez. 89.

Bonn, d. 3 Dez. 1889.

Figure 13—Hertz's Letter to Herr Huber, Reproduced by Courtesy of the Deutsche Museum, Munich

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TRANSLATION

Bonn, Dec. 3rd, 1889.

Dear Sir:

Replying to your kind letter of 1st, I have pleasure in giving you the following particulars:

Magnetic lines of force may be propagated just as well as electric, as rays, if their vibrations are sufficiently rapid: in this case they proceed together, and the rays and waves dealt with in my experiments could be designated magnetic as well as electric.

However, the vibrations of a "Transformator" or telegraph are far too slow; take, for example, a thousand in a second, which is a high figure, then the wave-length in the ether would be 300 kilometres, and the focal length of the mirror must be of the same magnitude. If you could construct a mirror as large as a Continent, you might succeed with such experiments but it is impracticable to do anything with ordinary mirrors, as there would not be the least effect observable.

With kind regards,

Yours ——

Hertz.

was as clear as crystal, his methods of attack were direct, original, penetrating. He operated with conspicuous courage. As an example may be taken his method of treatment of a spherical wave in a medium that is homogeneous except near the origin of co-ordinates. Lord Kelvin singled out for special praise his method of dealing with the problem of the elastic contact of two spheres. Hertz at first found difficulty in accepting the corpuscular theory of cathode rays, i.e., the theory advocated by Stokes and Crookes, and now confirmed, that they consist of particles projected from the cathode, in straight lines, at high velocities. He could not readily imagine corpuscles penetrating metals, and accordingly he was, for a time at least, inclined to interpret cathode rays as waves.

The laboratory in which Hertz worked at Bonn was in part of the ancient palace of the Prince Elector. At the time of the Roman-German empire the neighbouring city of Cologne was one of the Electoral principalities, and the Prince Elector was also Archbishop of Cologne. But Cologne, being a free city, did not permit the Archbishop to reside there except for clerical functions. There being no palace for him in Cologne, in accordance with the predilections of princes of Bavaria for castles in those days, he provided himself with one at Bonn. From the year 1320 this was the constant residence of the Archbishop of Cologne. In the nineteenth century, when the Rhineland went to Prussia, the University of Bonn was endowed with the archiepiscopal palace. Clausius resided there, but Hertz preferred to have a private residence elsewhere in the vicinity.

At Bonn, in July, 1892, Hertz was attacked by a pernicious illness, attributed to a carious tooth that caused ulceration of the upper jaw. Repeated operations, a sojourn in the Riviera in the spring of one year, and a holiday at Reichenhall in the autumn of the next, so improved his condition that the danger was believed to have passed. General symptoms of blood-poisoning next showed themselves, and extended to the bones. Nevertheless, until the middle of December, 1893, he delivered his lectures and he prepared new experiments. The disease, however, reasserted itself and on January 1, 1894, he died.

Amongst those who knew him best, the remembrance that remains of him is of a man of amiable disposition, social, genial, a good lecturer, possessed of singular modesty, who gave himself no airs as of a great professor, and who, even when speaking of his own discoveries, never mentioned himself. When the Royal Society presented him with the Rumford medal, he silently disappeared from Bonn for a few days—none knew why—and he returned as silently. The habit he formed early in life of solving difficulties for himself continued with him; he preferred, upon occasion, to puzzle things out in loneliness in the laboratory. His decision to follow pure science instead of a technical career was faithfully kept, and yet the importance of the part he played in the ultimate technical advance in electrical science is beyond measure. It can be definitely stated that concerning the future employment of Hertzian waves for telegraphy and telephony he had no anticipations. For there exists a letter written by him to one, Herr Huber, who wanted to know whether there was a prospect in that direction. Hertz regarded it as impracticable. His reply, which is reproduced in Figure 13, was to the effect that it would need a mirror as large as a continent.

An Automatic Telephone System for Rural Exchanges

By L. J. SALTOFT

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Introduction

IN rural districts, where residents are scattered over wide areas with consequent necessity for the installation of many small telephone exchanges, it often happens that the location most favourable from the point of view of the economical planning of the line plant is unsuitable for the accommodation of the operating staff. Automatic rural exchanges, which obviate the necessity for staff accommodation, therefore, become a necessity.

Automatic rural exchanges are proving of value also in decentralising important city exchange areas which often serve extensive localities where telephone lines, installed as required, are not very economical on account of excessive length. These lines gradually increase in the outlying parts of the exchange areas, and necessitate the installation of large and expensive cable plants in order to avoid a too heavy loading of the aerial routes. In cases where operating companies are facing the problem of projecting new and expensive cable plants under such conditions, it becomes necessary to consider the possibility of reducing expenditures on cable plant through decentralisation by means of small rural automatic equipment connected to the city exchanges through a limited number of junction lines.

It is for such reasons that the Copenhagen Telephone Company for a long time had been awaiting an opportunity to make a trial of rural automatic telephone exchanges. The occasion presented itself in a little village, Bröndbyvester, situated approximately nine English miles west of Copenhagen. The area covered by this 100-line exchange, which formerly was of the local battery type, is shown in thick lines in Figure 1.

It will be seen that the village itself is situated in the northern part of the area, and originally the telephone density was highest in this vicinity with very few subscribers' lines running toward the coast. However, development of the territory during recent years necessitated the installation of a relatively large number of lines towards the coast in the southern part of the central office district. The result was that the pole line from Bröndbyvester southwards, having become too heavily loaded, had to be replaced by a cable. In view of the fact that difficulties had arisen regarding the question of attending to the service in the old local battery exchange, it was decided to install an automatic rural equipment, the location of which is shown in Figure 1 by a black rectangle.

On local traffic in the Bröndbyvester district, the introduction of the full automatic system offers to subscribers the advantage of 24-hour interrupted service, a benefit not previously provided. As regards the control of the traffic outgoing from and incoming to Bröndbyvester, this exchange is operated as a sub-office to the nearest larger local battery city exchange; i.e., Glostrup. This means that all traffic other than local in Bröndbyvester exchange has its switching centre in Glostrup manual exchange, and is there controlled by the operators.

Requirements

The automatic equipment had to be arranged so as to work in conjunction with the Glostrup manual local battery exchange. In calling for tenders, the following requirements were laid down:

1. The system must work on a line resistance of 1,000 ohms and on a minimum insulation resistance of 10,000 ohms between line wires, and between each line wire and ground. (This was required on account of the long aerial lines used in the rural area for subscribers and for junctions to the city exchange.)

2. The system, in any case, must work with 24 volts potential in so far as the line is concerned; i.e., line, transmission bridge and dial response relays must work on 24 volts.

3. The system must work in connection with a local battery exchange; i.e., an automatic subscriber in Bröndbyvester must be able to select a free 2-way junction to the manual city exchange and the city operator must be able to call the Bröndbyvester subscribers by dialing over one of the idle 2-way junctions.

Furthermore, in short and long haul toll service, a facility was required whereby the toll operator, after having dialed and obtained the wanted subscriber in the rural automatic area, must be able to cut in on a busy connection previously established by this subscriber, offer a toll call and eventually also break down the existing connection, thus giving preference to toll connections.

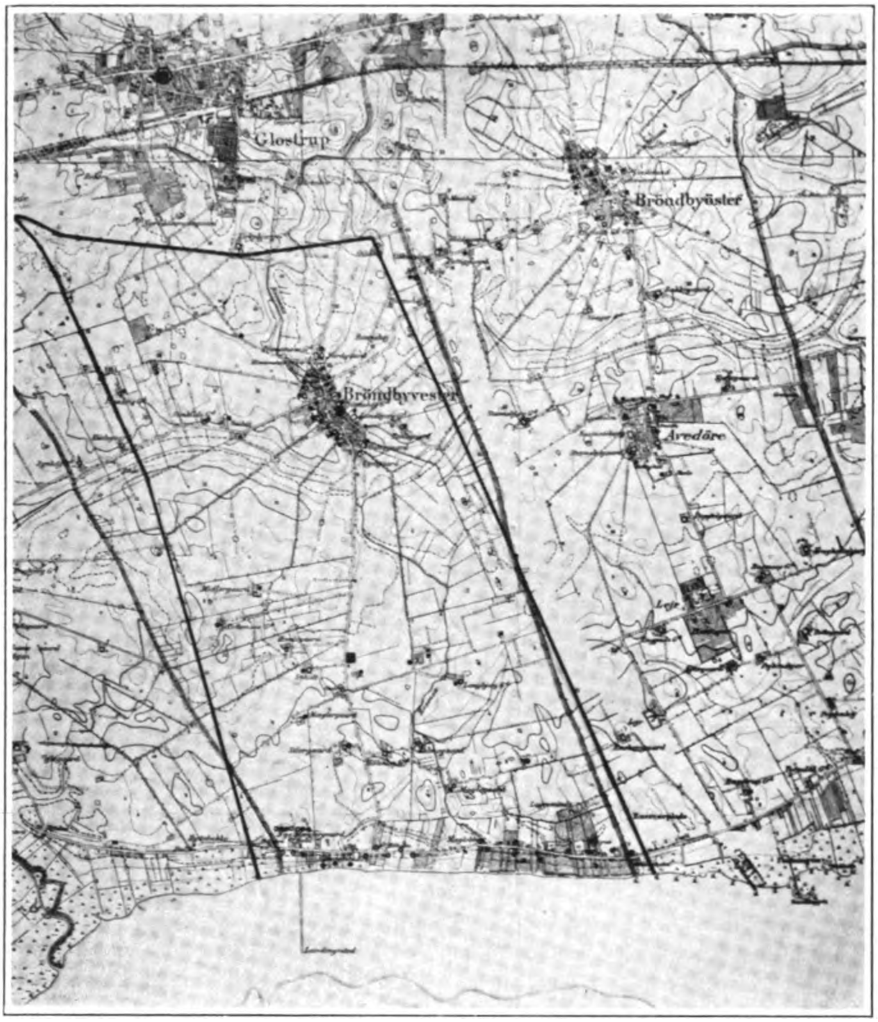


Figure 1—Map of Bröndbyvester

Supervisory signals must be given both to city and toll-board operators engaged in the toll connection after the Bröndbyvester automatic subscriber hangs up his receiver, regardless of whether he has called or was himself called by the city exchange.

4. Provision must be made for automatic alarm devices by means of which the automatic rural office can send alarm signals to the city exchange over one of the junctions, when important failures, such as in the exchange battery voltage, exchange ringing, etc., occur.

5. Short-circuited subscribers' lines must be removed automatically from service so that apparatus will not be occupied for an unduly long time. (This feature was required because of the open wire circuits in the rural districts.)

As a result of the offers submitted, the Copenhagen Telephone Company decided that for trial installation and practical investigation of the operation of automatic rural exchanges a 100-line Standard Electric equipment with an ultimate capacity of four hundred lines should be ordered since it fulfilled all the requirements enumerated. In general principles, the exchange which was furnished is similar to the well-known International Standard Electric Rotary Machine Switching System with motor driven switches except for adaptation of the equipment to the special requirements of automatic rural exchange operation.

Description of Equipment

Figure 2 shows the junction diagram of a 200-line full automatic rural exchange working in connection with a local battery city exchange, the line finder side being shown only for one hundred subscribers' lines. The latter are cabled to one hundred arc contacts on the connectors, the respective arcs being connected in multiple in the well-known manner with silk ribbon cable. The subscribers' arc contacts are grouped in two levels of fifty contacts, each set of contacts consisting of five terminals, arranged vertically, corresponding to the five brush arms of the line finder and the selector brush carriages forming the link circuit. There are at present in all twelve link circuits for the one hundred subscribers connected to Bröndbyvester.

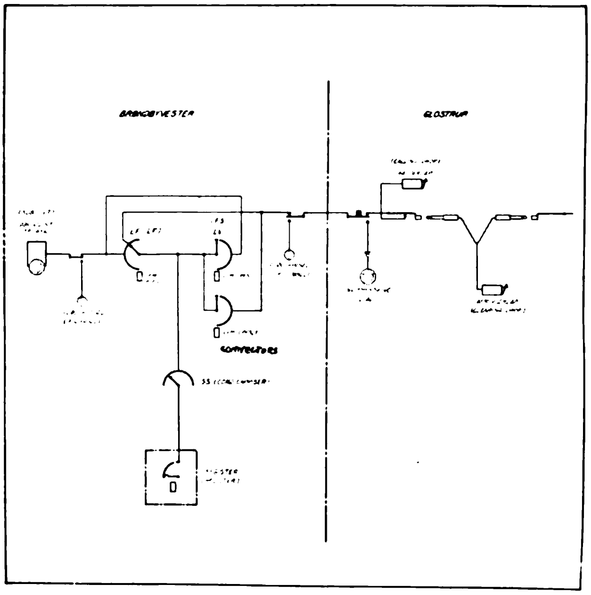


Figure 2—Junction Diagram

Each link, as shown in Figure 2, consists of one line finder and two or more selectors, according to whether the capacity is for two or more hundred lines. The construction of the line finders and selectors is practically the same. They both have a brush carriage with two arms and five double brushes on each arm. The two arms are mounted 180 degrees from each other. Thus, when the brush carriage rotates, it hunts first for the fifty subscribers situated in one of the two levels, then for the other fifty subscribers situated in the other level. The contact arcs have one hundred and two contacts (fifty-one in each level), the first contact in each level being reserved for routine test purposes. The selector is arranged with a home position.

The first ten terminals of the multiple arc belonging to the subscribers numbered 300-399 are reserved in Bröndbyvester exchange for junctions. These ten terminals can be used for nine junctions, the tenth terminal being required for stopping the selector on it and sending a busy tone in case all junctions are busy.

All link circuits, as indicated in Figure 2, are cabled to two contact banks each consisting of twenty-four sets of contacts. Each set of contacts contains eight terminals arranged vertically. Two such sets of eight contacts belong to each link circuit. The capacity of this arc is thus sufficient for twenty-four links. The arc with its brush carriage forms the "Link Chooser" associated with each register, by means of which the register involved in the call finds an idle link belonging to the group of one hundred subscribers where the call is originated. Three registers are now equipped in the Bröndbyvester exchange, but space is reserved on the frame for a fourth register.

The registers consist of the instepping relays and necessary counting relays for the selection control. Furthermore, the registers have test relays and other relays required for the control of the different classes of calls, in all about seventy relays of the Standard Electric flat type. There is also a sequence switch and a time alarm switch associated with each register circuit.

All switches are operated by means of electromagnetic clutches and gears of the improved disc type, energized in their respective circuits at given moments in the progress of the call. The gears engage in the drives mounted on the vertical shafts. The vertical shafts terminate with a bevel gear at the bottom, the gear engaging in a corresponding gear mounted on the main horizontal shaft which connects with a

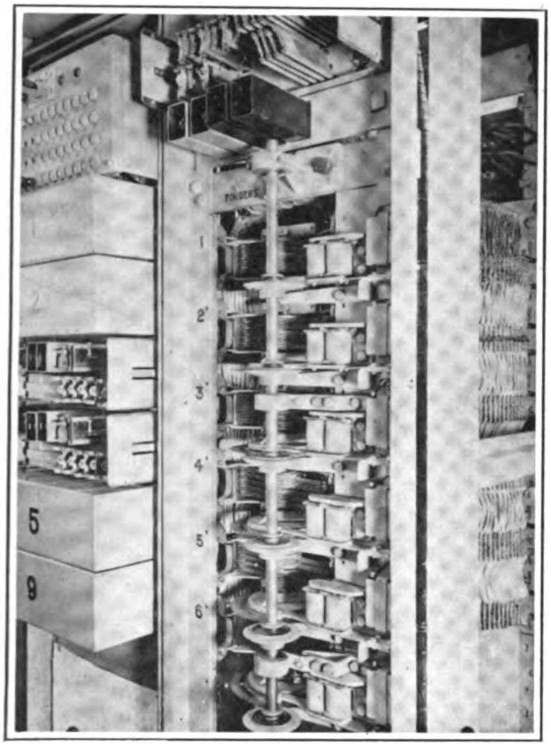


Figure 3—Bay Unit

$^{1}/_{16}$ H.P. 48-volt switch motor by means of a worm gear. Figure 3 shows a bay unit with six line finders on which is seen the Standard Electric gear driven devices now used.

If no switch clutch is energized, the vertical shaft revolves freely and the driven gears are kept away from the driving gears by the heavy back pressure of the clutch armature deflecting the former gear. When the clutch magnet of the switch is energized, the armature is attracted and releases the driven gear which, returning to its normal position, engages in the driving gear of the vertical shaft.

It should be noted that the switch motor starts up automatically when a call is originated, and runs during selection and release, but not during conversation or when the equipment is normal.

Apart from the switches already mentioned, the equipment contains the necessary subscribers' line and cutoff relays and starting relays, link circuit relays, signaling devices, etc. The whole of the equipment is enclosed in sheet iron cabinets with easily removable doors in order to permit access to the apparatus from both sides.

There are in all four bays, one for line relays, two for line finders and final selectors and one for registers and signaling devices. There is also a separate bay, constructed by the Copenhagen Telephone Company itself, for charging machines and power board.

The subscribers' sets are of the ordinary common battery type with dials for selecting local numbers or trunk lines (see Figure 4).

Subscribers' telephone lines are numbered from 200–299 and from 310–399, and it is, therefore, necessary to dial in all three digits for local selection. Numbers "0" and "9" are reserved for calling on junctions: "0" for connection to Glostrup exchange—the main city exchange for Bröndbyvester—and "9" for eventual connections with another rural sub-exchange of Glostrup. Furthermore, the number "1" is reserved for special services.

In Glostrup central office (see Figure 2) the trunk line ends in a drop and an ordinary jack which operates on receipt of a call from Bröndbyvester. In Glostrup the connection is then put through by means of a double cord circuit, containing a bridged clearing out drop signal which operates when the Bröndbyvester subscriber hangs up his microtelephone. In order to enable the operators in Glostrup to call subscribers in Bröndbyvester, each position is equipped with a dial and one dialing key for each junction. Operation of this key connects the operator's dial in the junction as soon as a link circuit and a register have been obtained by plugging into the jack of the corresponding junction. The key also enables the operator to cut in on a busy subscriber's line in Bröndbyvester, offer a toll connection and eventually break down the subscriber's local connection in

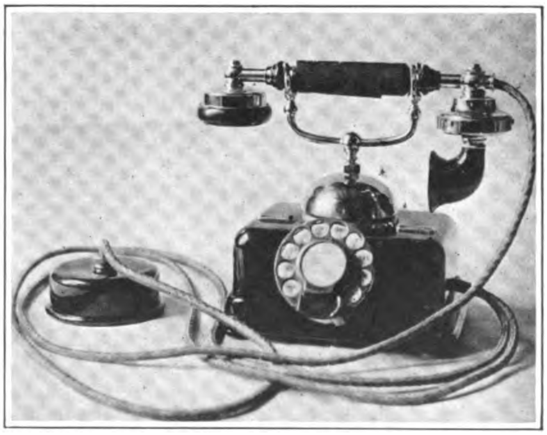


Figure 4—Subscriber's Set

order that toll service may be given preference over local connections.

The system is arranged for P.B.X. hunting and revertive party line calling.

If a wrong number is dialed, a special interrupted dialing tone signal is given to the subscriber, in order to acquaint him with this fact.

Handling of Faults

An arrangement is provided for signaling to the main exchange over one of the regular trunks the occurrence of certain faults at the rural installation. The selected trunk is taken over contacts of a relay in the fault alarm circuit which when operated disconnects the rural side and connects the signaling apparatus towards the main exchange.

Main fuse failure, ringing failure and shaft failure, have been considered as faults of major importance. Individual circuit fuse, voltage alarm and operation of the common time alarm associated with the register circuits, indicating the fact that all registers have been engaged for thirty seconds, are regarded as of secondary importance.

Each subscriber's line and junction circuit is provided with a special permanent loop relay, which enables a short-circuited or grounded line or junction to be eliminated from service and prevents it from interfering with the equipment. Such a faulty line or junction otherwise would unduly occupy links and registers until the fault had been cleared. In order to enable the operators in Glostrup from time to time to determine whether there are permanent loops on the lines or equipment in Bröndbyvester, they can go in on one of the junctions, connect to the Bröndbyvester equipment and dial a definite number. If there are one or several permanent loops in the Bröndbyvester area, the operator receives a special tone in her receiver.

Outgoing Call to Main Exchange

When the single digit "0" is dialed the particular switch in the link to which the outgoing junctions are connected must be advanced from normal to the first terminal in readiness to hunt for a free junction. During the time the switch is rotating the number of steps made is registered by the counting relays and when the last junction is reached hunting is stopped.

Toll Connection

The register circuit is provided with means for enabling the toll operator to listen-in on a busy connection and to break down such a connection if necessary. Further, a check is provided to ascertain whether or not ringing current shall be sent to the wanted subscriber's line after breaking down of the local call.

Ringing Current

Ringing current is generated by means of a transformer. The centre point of the primary winding is connected to battery through a low resistance retardation coil which is shunted by a 4 M.F. condenser. The outside windings of the primary are connected through an interrupter to ground. The interrupter closes each winding alternately; a ringing current is generated with a frequency of approximately 17.6 periods per second. The secondary winding of the transformer is connected to battery and is shunted by a condenser of 8 M.F. capacity.

Dialing and Busy Tone

Dialing tone for each register is provided by means of an individual transformer, the secondary windings of which are connected in series with the instepping relay. The primary winding of the transformer is connected to ground through an interrupter which creates a tone of 133 periods per second.

The busy tone is supplied to the calling subscriber over the same transformer in the register circuit, but the primary winding is in this case connected to ground through an interrupter which creates a tone of 400 periods per second.

Routine Tests

Simple means are provided for obtaining connection with any particular link circuit or any particular register. The circuits are tested by sending calls from a regular subscriber's instrument to a test number. On each link circuit a key is provided which disconnects the link circuit from the common starting circuit and connects it to the routine test circuit.

Last P. B. X. LINE

When P.B.X. hunting is provided each group is followed by a dead terminal. If all lines in the

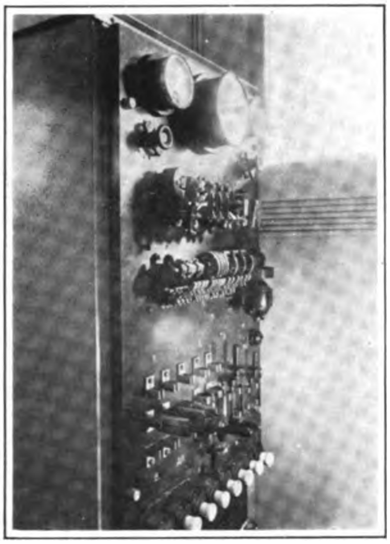


Figure 5—Power Board

group are found busy, the hunting selector is stopped on this terminal.

Power Arrangements

In the Bröndbyvester exchange two different voltages are used for the operation of the equipment; i.e., 48 volts for the switches and certain relays, and 24 volts for the line relays, link supervisory relays (microphones) and instepping relays.

The main power supply in Bröndbyvester is 380 volts A.C., 3-phase, 50 cycles. Inasmuch as the power-leads there, as in most other rural districts, are run on aerial routes and may often fail, the Bröndbyvester exchange is supplied with two 48-volt accumulator batteries, one being charged while the other is discharging. Each battery has a capacity of 300 ampere-hours. The 24-volt supply mentioned previously is obtained by inserting a small battery of C.E.M.F. cells of 24-volt, 24-ampere-hour capacity in the power circuit.

The advantage of using such a battery of C.E.M.F. cells is that it does not require any special attendance. The battery is charged each time there is a connection established in the exchange. Experience has shown that ten C.E.M.F. cells are satisfactory.

The power machines consist of a motor-generator set of 2.2 H.P., 3-phase, 380 volts-1,200 watts, 80 volts. In addition, there is a small regulating motor of 1/8 H.P. which is operated from the battery on discharge. To avoid supervision of battery charging, an automatic cut-out is arranged in the charging circuit. In case the main power supply should fail during charging the battery is cut out, and also is cut in automatically when the main power supply is restored. This is accomplished by means of the 1/8 H.P. regulating motor in connection with a phase break relay having special voltage and current coils.

The controlling motor, when running, governs the various manipulations by means of a specially arranged sequence switch, so that all manual regulation of the dynamo voltage is avoided.

Figure 5 shows the power-board and the motor-generator set; Figure 6, the accumulator room with one 40-volt battery on each side of the middle aisle and one C.E.M.F. battery at the end of the aisle.

Building and Layout

Figure 7 shows the floor plan of the building for the automatic rural exchange. The interior measurement is 9 x 4½ metres and is intended to include the space necessary for machine

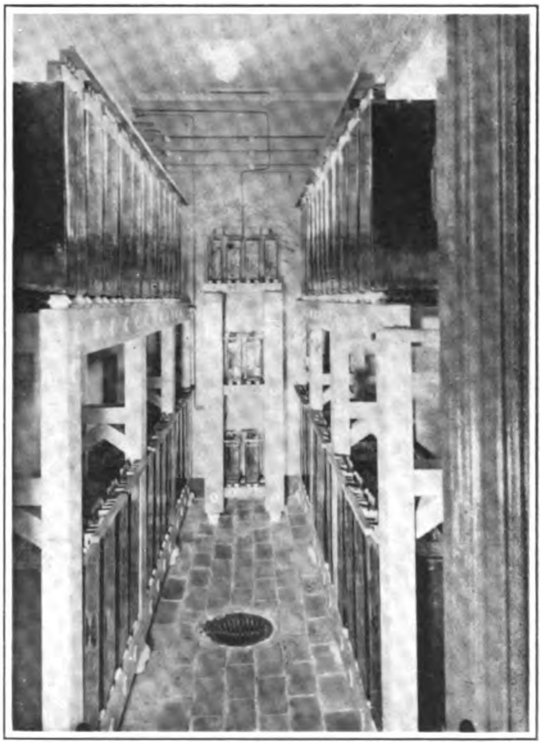


Figure 6—Accumulator Room

switching equipment for four hundred subscribers' lines. From the main entrance door there is direct access to the main frame room where all necessary cross connections for connecting subscribers to the exchange can be carried out.

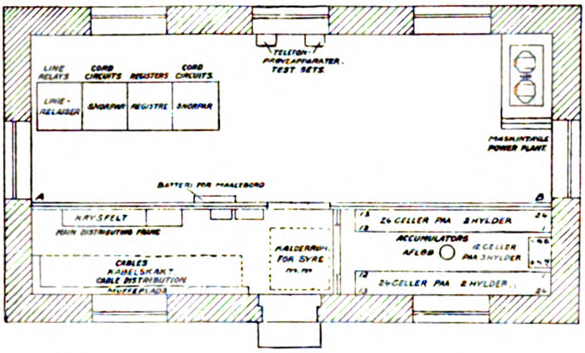


Figure 7—Floor Plan of Rural Exchange

In this room the wire-chief's desk also is installed. This desk is combined with a lamp box for permanent glow lamps indicating short-circuited or grounded lines. The main frame room is accessible to a concrete cellar which serves as a storeroom where acid and distilled water intended for the accumulators can be stored without being exposed to frost.

The battery room is separated from the main frame room by a double door and is specially ventilated. In the switchroom itself, which is separated from the main frame room by a door, the automatic switchboard is installed starting from the left hand side of the room. The frames enclosed in the iron cabinets have a capacity of two hundred lines. At the right-hand side of the switchroom the power plant is installed, enclosed in a similar iron cabinet.

Figure 8 shows the exchange building itself, which is provided with windows of Monier glass six feet from the ground. The house is built of brick. Special consideration was given to humidity conditions and temperature variation. As the thatched roof used presents danger in case of fire, special precautionary measures were taken, the ceiling of the switchroom being made of stamped clay. Such a roof can burn without the fire gaining immediate access to the switchroom. As a protection from lightning, a net of copper wire is drawn under the roof. By means of four external connections soldered to the inside net, connection is made to the main earth bar which is carefully embedded adjacent to the building. Connections to earth are made also from the main, switch and machine iron frames. The building is not centrally heated but, by means of a thermostat, electric lamps placed in the switch cabinets are cut into the power supply circuit automatically whenever the temperature in the cabinets drops below 6 or 8 degrees centigrade. The lamps are extinguished when the temperature rises again. To provide for high humidity all wires and cables have an especially good black enamel finish.

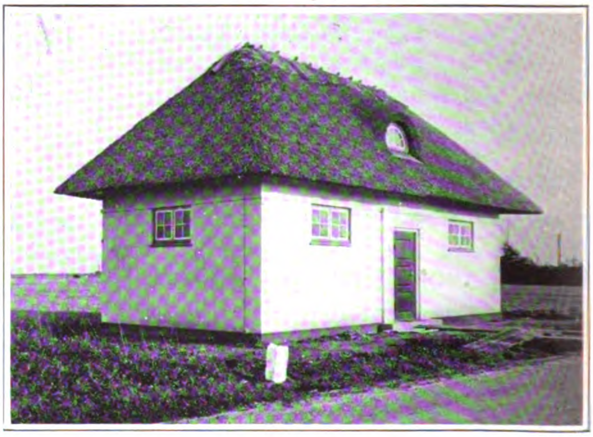


Figure 8—Rural Exchange Building

Results of Operation

The Bröndbyvester rural exchange was placed in operation at the end of July, 1926, and has been operating very satisfactorily.

The 7-A Rotary Machine Switching System in New Zealand

By E. A. SHRIMPTON
Standard Telephones and Cables (Australasia), Ltd.

NEW ZEALAND consists of North Island, South Island, and several small islands in the South Pacific. It has a total area of 104,900 square miles, and it occupies an important position about 1,200 nautical miles to the south-east of Australia. Including the outlying islets and the Ross Territory, the boundaries stretch from the tropics to the Antarctic. The climate is generally equable, mild and salubrious, as might be expected within latitudes corresponding to those of the Mediterranean region between North Africa and the South of France.

Mount Egmont, 7800 Feet above Sea Level—New Zealand's Fujiyama

Among the most striking physical characteristics of New Zealand are its mountains. From the mountains rise numerous rivers. This feature, together with large and small lakes and glaciers, which nature has provided for storage, has placed the country in possession of enormous reserves of energy awaiting exploitation. The country is destined to become one of the manufacturing centres of the southern hemisphere.

The total estimated power of schemes of 1,000 horse-power and over, on a 50 per cent load-factor, available in the North and South Island, respectively, is said to be 776,000 and 4,110,000. The Government has made a beginning with power development, and has brought some schemes into operation in comparative proximity to the centres of industry, but they represent only an infinitesimal portion of the energy available.

The population of New Zealand and dependencies, including Maoris and residents of Cook and other Pacific islands, is about one and a half millions; nearly 95 per cent of this total is of the British race. The Maori population is about 63,000. The Maoris are a superior race of Pacific islanders. The educated Maori competes successfully with his white brethren. He has held some high positions in the land; he has even represented white constituencies in the House of Representatives, and is a born orator.

In New Zealand, sport is so pleasantly associated with marvelous scenery that visitors from all parts of the world acknowledge this country to be "The Sportsman's Paradise." Railroads and motoring roads give easy access to the hundreds of streams and lakes in which acclimatised trout and salmon attain a size far surpassing the measurements and weight of their largest ancestors in the northern hemisphere. It is similarly easy for sportsmen to make their sallies in launches for large swordfish and Mako shark. Many of the places where deer, wild pig, and feathered game are plentiful can be reached without difficulty. Some of the deer-stalking country is, of course, rugged, but the keen sportsman likes to work for his trophies.

Primitive Communication. Maori Women greeting by rubbing noses

Telephones were used in New Zealand as far back as 1880 when Edison and Bell instruments were installed for bringing the "outback" into touch with the telegraph system. They assisted materially in opening up the back country for settlement. Figure 1 illustrates this first type of telephone used in New Zealand. The resistance of the bell coils was 100 ohms. Wet Lechlanché cells were employed; they were contained in a battery-box, not shown in Figure 1. The telephone now enters very largely into the business and social life of the Dominion.

The number of telephones per 100 of the population is 9.5, a figure which places New Zealand well up in the list of "Telephone Development of the World, by Countries." The number of telegrams forwarded annually per head of population is nearly five—the highest in the world.

New Zealand is also well placed in the list of "The Number of the Population per Motor Vehicle, by Countries." The United States of America leads with 5.8, followed by Canada 12. and New Zealand 12.5.

The first telephone exchanges were installed in 1881. They were "Earthworking" with locally made magneto switchboards, and Edison and Bell instruments. The exterior of the Wellington (New Zealand) Telephone Exchange as it existed in 1887, is illustrated in Figure 2. At that time it had 550 earthworking lines. The cables shown as "lead-in" were 30-core rubber covered wires. The wires going skywards in Figure 2, terminated on a hill. Some of the spans were more than 1,000 feet in length. The interior of the Wellington (New Zealand) Telephone Exchange in 1887 is illustrated in Figure 3. The racks on top of the switchboards carried serrated lightning protectors followed downward by drops, jack-fields, and transfer board. The resistances of the drop coils were about 100 ohms.

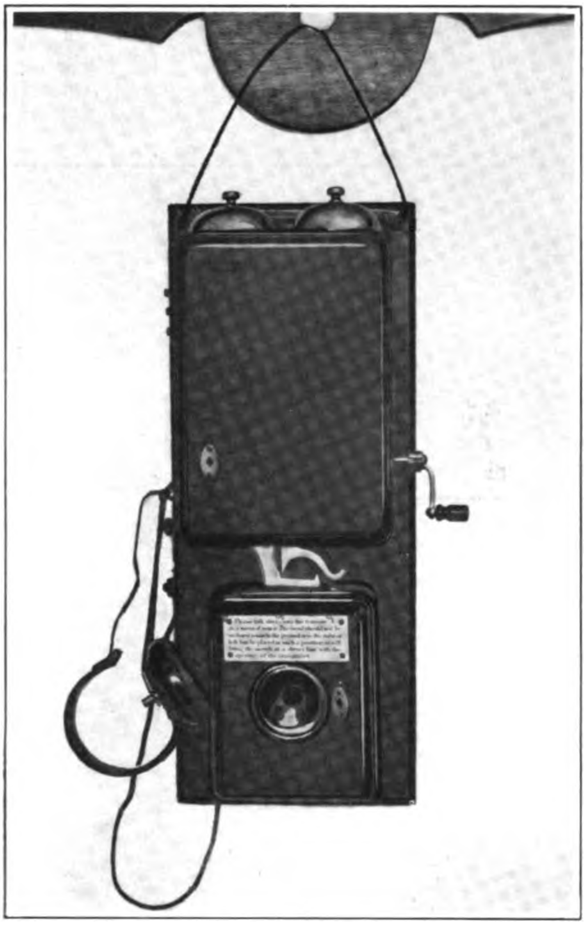


Figure 1—Example of the First Telephones Used in New Zealand

and were always in series with the line. Since then the telephone exchange business has increased steadily, the Administration passing through various stages and phases as in the older countries of the world. Western Electric standard switchboards, and magneto telephones having solid back transmitters, later replaced locally-made switchboards and Edison and Bell telephones.

In the early nineties, trolley trams were introduced which caused, with feverish haste, the general conversion of earth-working to metallic circuit. About this time the exchanges at the four chief centres had grown too large for the traffic to be handled by non-multiple switchboards. Consequently, Western Electric branching multiple switchboards were installed, and a little later these were installed also in various provincial towns. Thereafter the Administration was faced with extensive modernisation of its entire telephone exchange equipment. The branching multiple switchboards had long served their period of usefulness and several had more lines connected to them than the estimated ultimate capacity. The question of the hour was, "What is it to be, manual or automatic?"

To help in solving this problem the Administration sent a representative to the United States and to Europe with instructions to enquire into and report generally upon the trend of events in older countries. After studying his report it was decided that automatic exchanges would give the required service for small and large communities in New Zealand.

In 1913, tenders were invited for two multi-office and four single-office areas. On receipt of

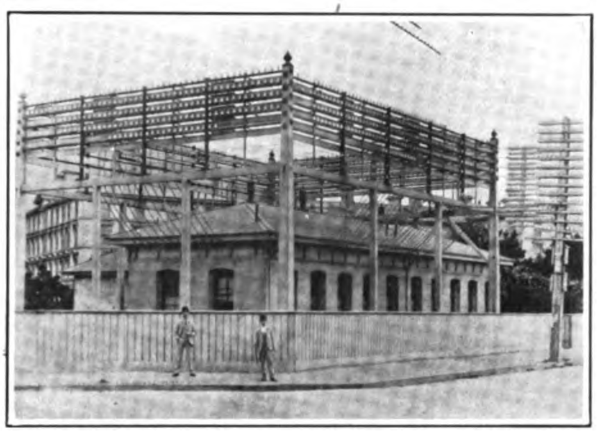


Figure 2—The Wellington Telephone Exchange in 1887

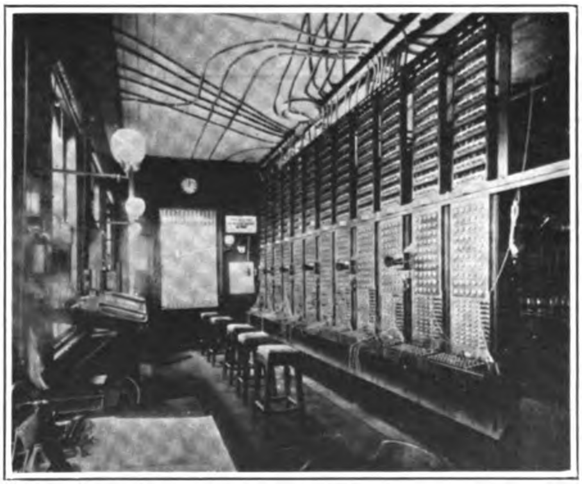


Figure 3—Interior of Wellington Exchange in 1887

the tenders, the Administration engineers very carefully and exhaustively studied the services that were offered and finally selected the Western Electric No. 7-A Rotary Machine Switching System. Early in 1914 it was decided to place the No. 7-A Rotary System in two more multi-office areas (six offices) and another single office area. On the announcement of this decision, criticisms were levelled at the Department for adopting, as it was alleged, so extensively a practically untried system. This criticism eventually proved to be entirely unwarranted, as will be seen from what follows.

Before suitable buildings could be provided for housing these seventeen exchanges, and before any installing work was done, the war came and everything was dropped but the main chance. New Zealand vigorously entered to assist the Empire. An indication of the magnitude of New Zealand's efforts is that ten per cent of the population fought overseas. During the war, a certain amount of installation work was done, but owing to the difficulty of getting apparatus—several ships bringing it were torpedoed—it could only be carried out in a partial manner. The want of suitable staff was also a deterring factor.

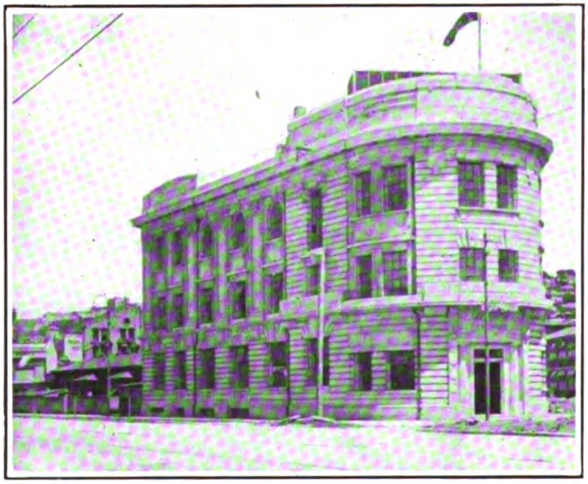


Figure 4—Stout Street (Main) Wellington Telephone Exchange in 1927

As already indicated, the New Zealand Government was one of the first to adopt the No. 7-A Machine Switching System. The installing was done by the Administration assisted by a small engineering staff forming part of the organisation of the manufacturer, The Bell Telephone Manufacturing Company of Antwerp.

The first exchange cut-over was such a success that the Administration was besieged by demands from other communities for the same equipment to be installed in their areas. In contrast with the 1887 exchange, Figure 4

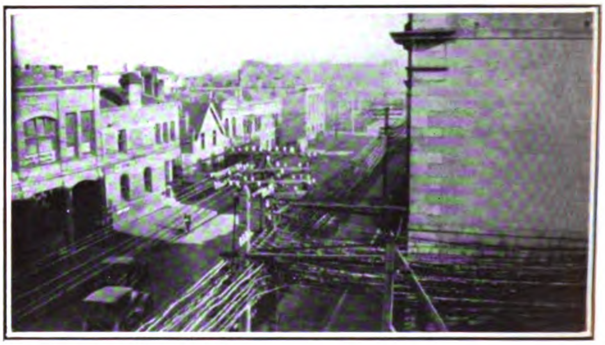


Figure 5—Overhead Cables at Christchurch, New Zealand, now being replaced by underground cables

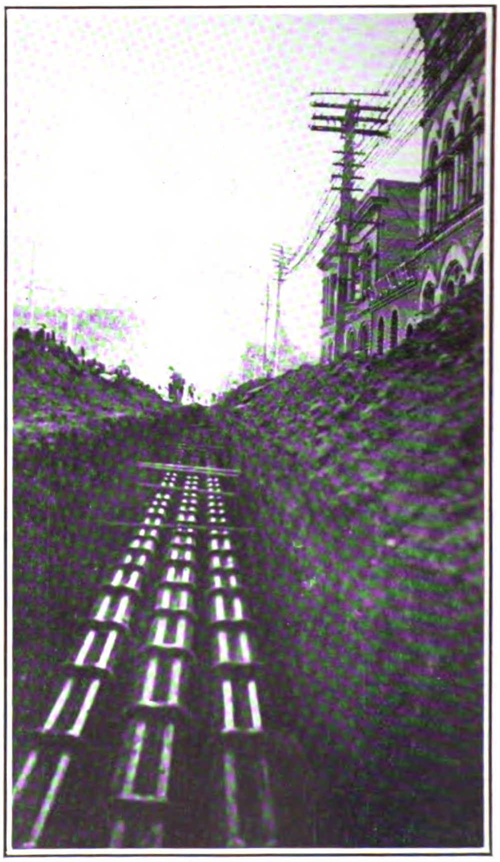


Figure 6—Underground Conduit, Christchurch, New Zealand

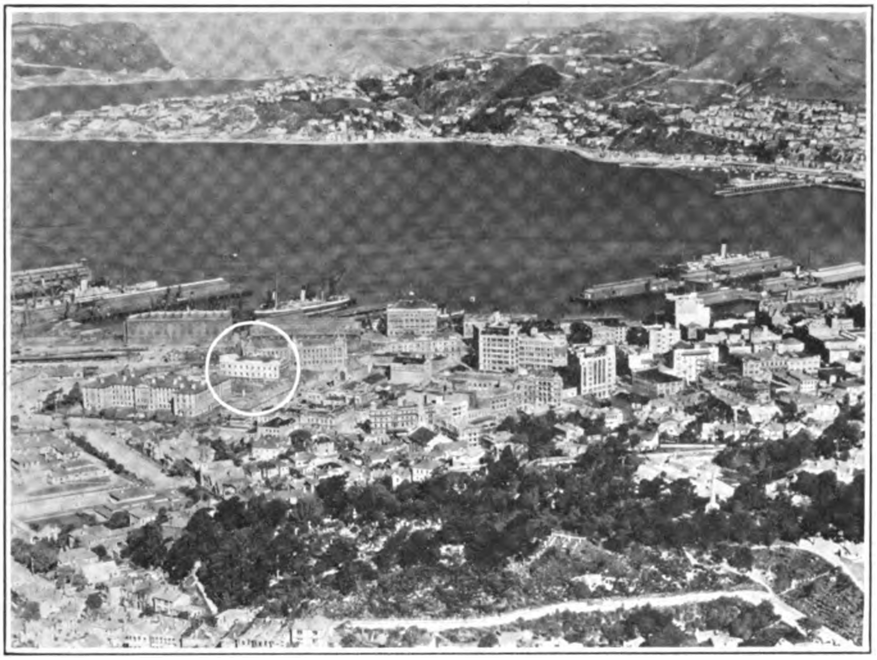


Figure 7—Wellington, the Capital of New Zealand. Stout Street Telephone Exchange is seen within the circle

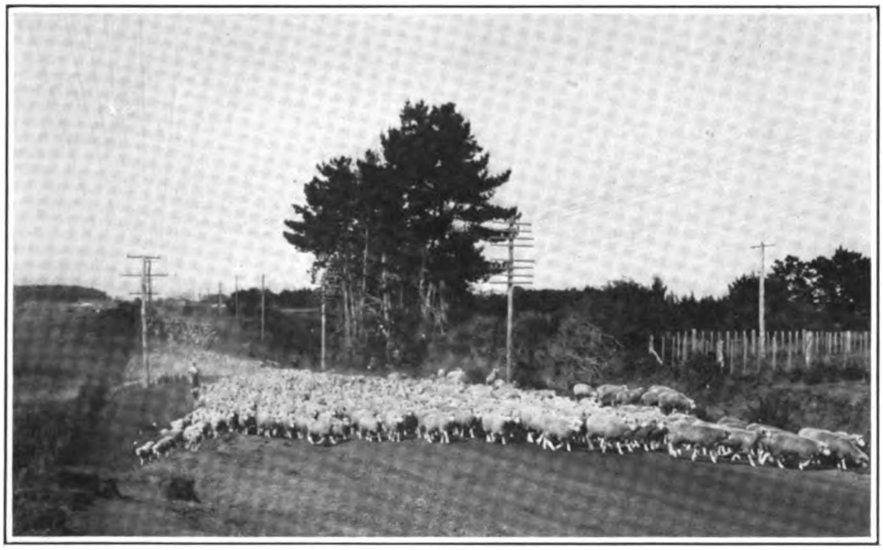


Figure 8—Telephone Trunk Line and Subscribers' Line, New Zealand

represents the modern Stout Street (Main) Telephone Exchange at Wellington (New Zealand). It contains about 8,000 lines of the Western Electric 7-A Machine Switching System. The road to the right is cut up for a new trolley car line. All cables lead in underground. To the left is the old exchange.

Up to the present, No. 7-A equipment is installed in New Zealand in the following areas:

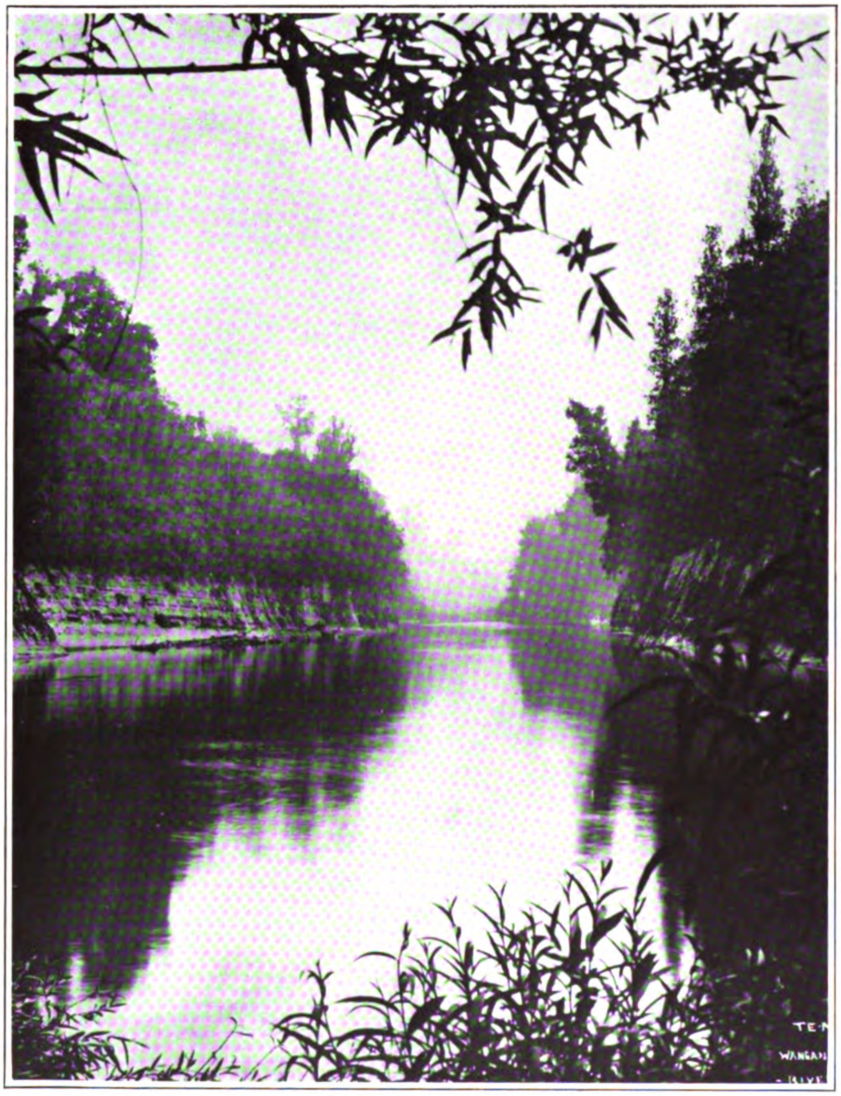
	Number of Offices	Number of Lines
Auckland	7	13,300
Wellington	5	15,800
Dunedin	3	6,300
Single Office	5	6,300

In the Christchurch area No. 7-A equipment for 9,000 lines (two offices) will be cut over in

1927. Overhead cables entering the Christchurch (New Zealand) Telephone Exchange are shown in Figure 5. These cables are of 100 pair dry core lead-covered type. They will all be replaced within the next few months by underground cables. Figure 6 represents the same locality, with the street opened up and conduits being laid for underground cables.

Extensions to equipment already in service are being installed at several exchanges totaling 2,500 lines, making a grand total of 53,000 lines. Enquiries have been received for another office of 1,100 lines for the Wellington area and others are pending for several exchanges throughout the country.

Wellington, the capital of New Zealand, is illustrated in Figure 7. The greater part of the business quarter of the city is to the right, beyond the picture. The Stout Street Telephone Exchange (Main) is the white building with the rounded end, seen below the bows of the steamer somewhat to the left of the middle of Figure 7. An idea of overhead construction in New Zealand can be obtained from Figure 8 which illustrates, on the left, power and lighting lines, and, on the right, telephone trunk lines and subscribers' lines.



Scene on the Wanganui River, New Zealand

International Chamber of Commerce Stockholm (Fourth) Congress

AT the Fourth Congress of the International Chamber of Commerce held at Stockholm from June 27 to July 2, 1927, international telephony was again discussed. At the Third Congress, which was held at Brussels in 1925, a Special Commitee was appointed to study and report upon this question, and since then a considerable amount of work has been done, mainly for the purpose of determining:

> What are the services actually open to the public?
>
> What is the opinion of business men with regard to the range, the audition and the rapidity of the service?
>
> What can be done by the Chamber to promote the widest possible extension of international telephone service?

One of the points specially noticeable at Stockholm was the general recognition of the immense importance of international telephony to business. At the group meeting the resolutions were proposed by a representative from Germany and they were seconded by one from Great Britain. At the plenary meeting they were proposed by Sweden, and supported by France. At both meetings they were carried unanimously.

It was greatly to be regretted that the Chairman of the Special Committee, Sir Martin Abrahamson of Copenhagen, was prevented, by illness, from presiding at the plenary meeting. His place was ably taken by Mr. J. S. Edström, Managing Director of the Svenska Elektriska, A.B.

Riksdagshuset (Parliament House, Stockholm) Where the 1927 Congress of the International Chamber of Commerce Was Held

The following are the Report of the Special Committee and the resolutions that were passed:

I. Reference of the Brussels Congress

At the Brussels Congress under the heading of "International Telephony," the following resolution was unanimously adopted:

> "*The Congress* of the International Chamber of Commerce recognizes the importance of an international telephone service in the promotion of commerce and trade between the nations, and the betterment of international relations.

> "*It Recommends:*
>
> "That the Council of the International Chamber appoint a special Committee to study and report to the Council upon the possibility of assistance by the Chamber in the improvement of existing international telephone facilities, and the widest possible extension of an international telephone service."

In the discussion attending the presentation of the resolution it was stated that the International Consultative Committee on Long Distance Telephony, made up of technical representatives of the various Administrations interested, had already undertaken the technical work; that it was not a question of the International Chamber of Commerce going over the same ground as the International Consultative Committee, but of aiding the latter with its advice, and giving it its support.

An International Telephone Committee was appointed, which has held several meetings, in all of which the Secretary General and other representatives of the International Consultative Committee have participated.

The following summarizes the activities of the International Telephone Committee, their findings and recommendations:

II. The Importance of International Telephony

In the consideration of the subject by the Committee, there early developed a growing realisation of the importance of international telephone service.

(*a*) As an effective instrumentality for removing impediments to international trade, and

(*b*) That the ability to secure speedy personal communication between distant cities should be a factor in stabilizing business through a more orderly and economic movement of goods;

(*c*) That effective telephone service tends to facilitate all the processes of production and distribution;

(*d*) That ability to communicate information quickly, tends to minimise the range of price fluctuations and thereby lessen the tendency to speculation;

(*e*) That any instrumentality which tends to stabilize business, facilitate its processes, and effectively extend the field of operations with consequent increase in the volume of trade, should lessen the difficulties of international settlements, as after all, all settlements have to be made ultimately in goods or services;

(*f*) That the ability to communicate voice-to-voice, easily and speedily, whenever desired or needed, cannot but be a means of improving social relationships and developing a common economic and social viewpoint which inevitably must have an effect in promoting a better understanding between nations.

III. The European Situation in 1922

To appreciate properly this problem of international telephony, it is necessary to know the conditions under which the telephone service in Europe was carried on up to the end of 1922.

At that time the outstanding features were:

(*a*) The construction and improvement of the telephone plants had been at a standstill during the whole of the war period.

(*b*) About forty self-contained local operating organisations, each also conducting a part of the international telephone service.

(*c*) No organisation controlling or coordinating the various local operating organisations which had to function together in handling international calls.

(*d*) No organisation of any kind which made plans for the international service as a whole.

(*e*) No common research, standard practice or technique of construction, maintenance or operation.

(*f*) No common agreement as to manufacture.

It is true that, even under these conditions, certain channels of international communication had been built up, but they were the result of individual effort, not the working out of any comprehensive plan.

Further difficulties to be overcome in the European situation arose out of the fact that long distance services were subject to budget and legislative requirements. The experience of established Government Departments up to that time (1922) had not demonstrated the necessity of the flexibility, now generally recognized, so essential to the conduct of great commercial services of a highly technical and rapidly expanding nature.

The European situation was, and is, rendered still further difficult by reason of the variation in language, in habits of the different nationalities and by international trade barriers.

IV. Formation of the International Consultative Committee[1]

Recognizing the need of a central body to consider international requirements, in 1923 a preliminary expert committee on long distance telephony met, at the suggestion of France, to enquire into the question of long distance telephony in Europe. This preliminary committee laid the ground for the work of, and recommended the appointment of an International Consultative Committee on long distance telephony composed of representatives of all European Telephone Administrations.

The International Consultative Committee on long distance telephony met for the first time in 1924, the official representatives of the Telephone Administrations of nineteen European countries being present.

As a result of enquiries initiated at this meeting, the Consultative Committee, at its second general meeting in 1925, outlined a first and temporary solution of the principal problems involved, after consultation with the experts of many business enterprises specialising in electrical and telephone matters.

During the International Telegraph Conference of Paris in 1925 the Consultative Committee received its official sanction, and was definitely asked to prepare model arrangements relating to the technical construction and operation of international long distance telephony. It was also decided that Administrations belonging to the International Telegraph Union should as far as possible follow these arrangements.

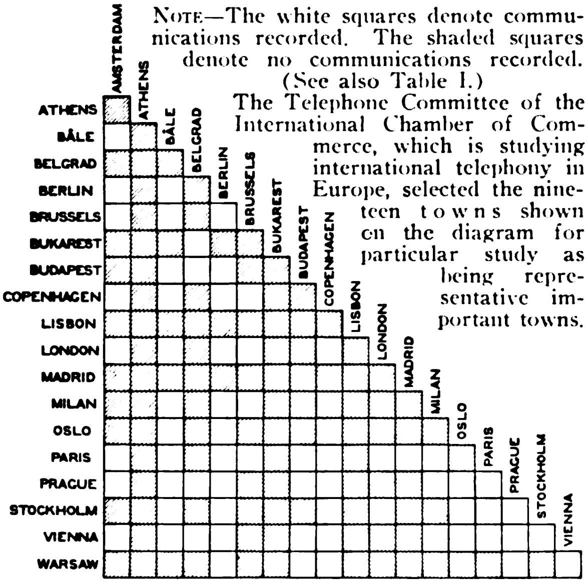
Since then the International Consultative Committee has made thorough investigation of these matters. Regulations for the operation of long distance telephones as recommended by it have been officially endorsed by the International Telegraph Union.

The International Consultative Committee has also studied costs so as to furnish a basis for the calculation of international telephone rates and charges.

The Consultative Committee for each group of new questions investigated appoints subcommittees of experts which have at their disposal information gathered from all over Europe and from the United States. Their recommendations are considered and, if approved, accepted, once a year at a general meeting attended by the official delegates of the Telephone Administrations.

V. Improvements Which Have Already Been Made Under the Programme of the International Consultative Committee

In 1925, the Telephone Administrations belonging to the International Consultative Committee outlined a comprehensive plan of international telephone cables between the larger cities in the several European countries. This plan provided for their construction being carried out during the period from 1926 to 1930.



NOTE—The white squares denote communications recorded. The shaded squares denote no communications recorded. (See also Table I.)

The Telephone Committee of the International Chamber of Commerce, which is studying international telephony in Europe, selected the nineteen towns shown on the diagram for particular study as being representative important towns.

Telephone Communication Between Nineteen Important Towns of Europe in 1927

Early in 1927 it was possible to see the first results of the efforts made by the Telephone Administrations belonging to the Committee:

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[1] For a more complete summary of the International Consultative Committee and its work, the reader is referred to an article in the July, 1927, issue of ELECTRICAL COMMUNICATION.

(*a*) New connections have been established between cities which formerly had no telephone connection between them (see Table I for examples).

(*b*) Numerous additional circuits have been placed in service on existing lines, which has noticeably reduced either the delay during hours of heaviest traffic or the daily delay (see Table II for examples).

TABLE I

The following shows nineteen of the principal cities of Europe and the total of the other eighteen with which each city had telephone communication in the periods indicated

	1925	1926	1927* (15th July)		1925	1926	1927* (15th July)
Amsterdam	5	7	8	London	4	5	7
Athens	0	0	0	Madrid	1	1	1
Basle	4	10	12	Milan	2	5	6
Belgrade	2	3	4	Oslo	3	4	6
Berlin	10	13	13	Paris	6	9	12
Brussels	3	6	7	Prague	3	8	12
Bucharest	1	1	1	Stockholm	3	4	8
Budapest	4	6	7	Vienna	3	8	12
Copenhagen	4	4	11	Warsaw	0	4	5
Lisbon	0	0	0				
				Totals of actuals	58	98	132
Percentage of actuals to possibles					17.0	28.6	38.5

Possibles = 19 × 18 = 342.

* Note: In this Table the figures for 1927, and the additions and percentages, are obtained from other sources, and are not included in the Report as issued.

TABLE II

A few examples of average delays in minutes during the busy hours. (*C. C. I. Records.*)

	1925	1927		1925	1927
Berlin-Paris	130	68	Paris-Brussels	180	180
Berlin-Vienna	143	62	Paris-Turin	180	10
Berlin-Stockholm	89	39	Stockholm-Copenhagen	8	8
Berlin-Prague	133	45	Vienna-Zurich	140	101
London-Amsterdam	61	34	Vienna-Cracow	90	74
London-Brussels	31	19			

(*c*) Communication has been improved on already existing connections between many cities through the use of improved apparatus and by the replacement of overhead lines by cables.

It is evident also that while the delays for ordinary service in Europe are still very much greater than those in the United States, as will be seen by reference to section VII of this report, the charges are considerably less. These delays in many countries in Europe can be reduced by "urgent" calls at triple rates, and by "lightning" calls, which provide immediate connection at ten times the ordinary rates.

Additional service features have been generally provided in connection with international service:

(*a*) Conversations exceeding three minutes are now charged for per minute extra, instead of by unit of three minutes.

(*b*) Fixed time calls and subscription calls are now allowed in business hours.

(*c*) "Notice" (préavis) calls have been introduced, permitting calls for a particular person by name.

On the recommendation of the Consultative Committee, the various Telephone Administrations, as a first step in improving the international service, will endeavour to provide facilities that will permit them to keep delays in the future within the following limits:

On circuits of less than 500 kilometers (310 miles) 30 minutes.

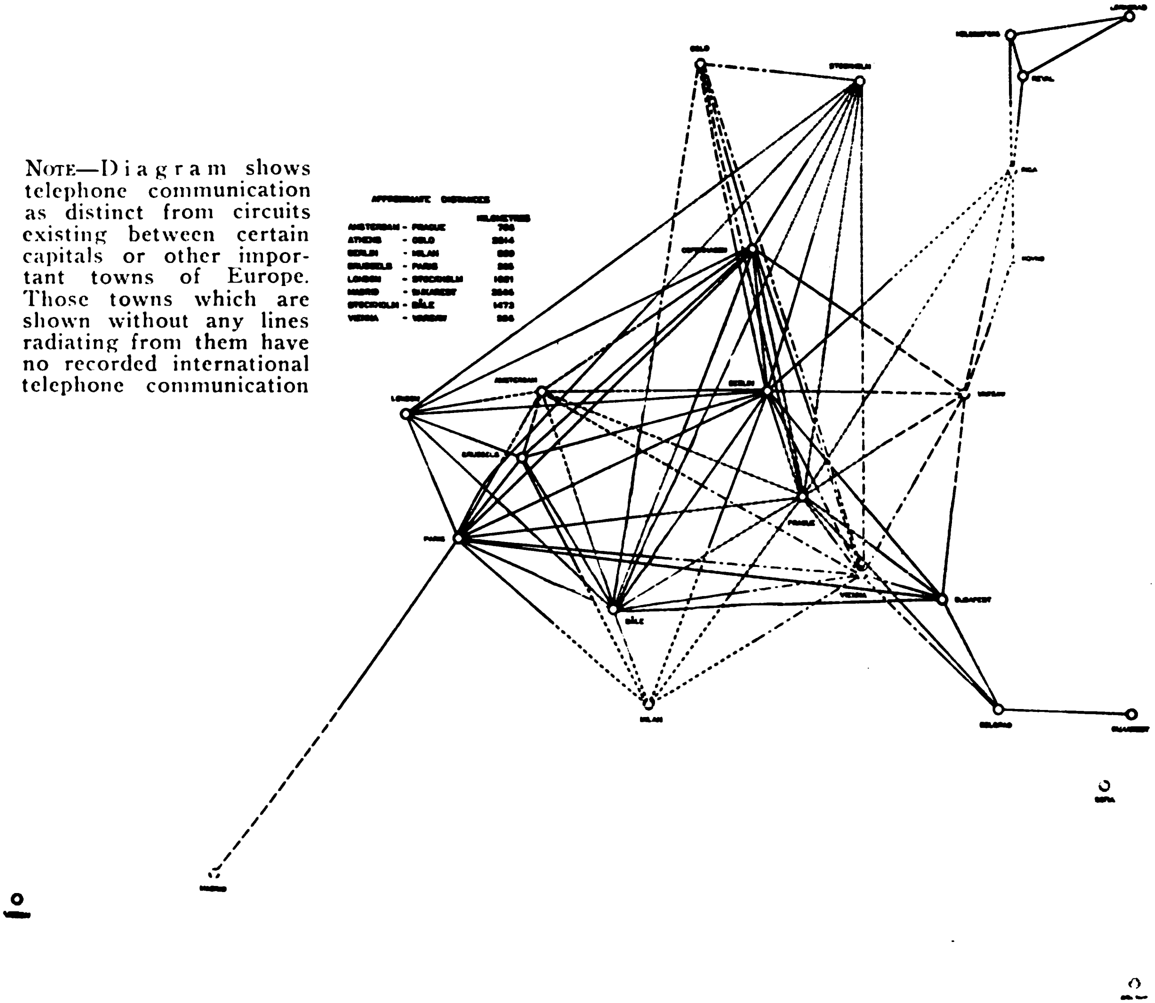
On circuits of less than 1,000 kilometers (620 miles) 60 minutes.

On very long circuits 90 minutes.

It should be noted that there is evidence that the extreme delays in obtaining connections in the past have formed an inhibition against the use of calls; that a latent demand existed is well demonstrated by the result of increasing the number of circuits between Paris and Berlin. Within three months after the addition of new circuits the number of calls increased nearly threefold.

VI. Enquiry Made by the Telephone Committee of the International Chamber of Commerce

Although the members of the International Telephone Committee had themselves considerable personal knowledge of the service, yet in order to develop concrete expression of the needs of users, a questionnaire was issued to the National Committees in 1926 and by them was passed on to individual firms and persons using or desiring international service.



NOTE—Diagram shows telephone communication as distinct from circuits existing between certain capitals or other important towns of Europe. Those towns which are shown without any lines radiating from them have no recorded international telephone communication

Telephone Communication Existing Between Certain Capitals or Other Important Towns of Europe

The attention paid to this questionnaire varied greatly, and while many replies were received from some nations, a surprisingly inadequate response was obtained from others.

Yet there was clearly indicated the general trend of feeling to the effect that industry and commerce required long distance telephony; that it was not satisfied with the extent, quality or speed of the international service then available; and that what was required was reliable and fast service with good audition over a very wide area.

VII. Reference to the Commercial Telephone Service in Use in U. S. A.

The Committee has investigated the long distance service in the United States. It has been able to secure considerable data through the American Section of the Chamber, and the Chairman of the Committee has made investigation in person during a stay of some weeks duration in that country. Some of the facts developed are outlined in the following:

Long distance service was in commercial use between New York and Chicago, 736 miles (1,187 kilometers), in 1892; between Boston and San Francisco, 2,760 air line miles (4,450 kilometers), in 1915.

The long distance service, as now effective in the United States, has been the result of an evolution extending over a number of years. It has been developed under a well defined business policy, some of the features of which are:

(*a*) Providing adequate audition between *all* points where there is an existing or potential demand for calls.

(*b*) The constant objective is to make the speed of connection between any two points as prompt, uniform and dependable as possible and approximately the same at *all* hours of the day. *All* calls are "urgent."

(*c*) In providing circuits, operating equipment, and operating staff, the primary consideration is the requirements of the user; that is, the volume of calls offered during the busiest hour of the day.

(*d*) There is no time limit to the use of the circuit except in the case of serious accidents to lines or other emergencies. Talks of from thirty minutes to several hours, without interruption are not infrequent.

It has been the constant aim to provide a long distance service which will be so satisfactory to the business man as to audition, dependability and speed, that it will be the communication medium to which he will instinctively first resort whenever need for communication arises.

The fact that a uniformly fast long distance service is available has led to its extensive use by business firms in selling goods to their customers in distant cities.

During the ten years from 1915 to 1925, while the population increased about 15 per cent and the number of telephones about 66 per cent the number of interurban calls increased 156 per cent.

This increasing utilisation of long distance service could never have taken place if adequate, speedy and dependable service had not been made available first, and its availability and utility demonstrated to business men.

About 900,000,000 interurban calls per year are now made in the United States. About 70 per cent of these are for relatively short distances, and the average speed of connection of these calls is less than one minute, the calling party waiting at the telephone for completion of the connection as in the case of a local call.

The remaining 30 per cent, or about 270,000,000 calls, are handled through toll boards, at an average speed of connection of four minutes, including calls for designated persons (préavis or notice calls).

Over routes carrying relatively heavy traffic and between large cities, in some cases for distances of over 1,000 miles (1,600 kilometers), about 70 per cent of the connections are completed within two minutes, the average speed being less than five minutes, while about 97 per cent are completed within ten minutes.

The transcontinental calls between New York and the larger cities on the Pacific Coast, an air line distance of over 2,500 miles (4,032 kilometers), are connected during business hours on the average in ten minutes. Calls between Chicago and these same cities on the Pacific Coast, an air line distance of over 1,740 miles (2,806 kilometers), are completed on the average in six minutes, during business hours.

To summarise, this long distance service affords adequate audition and high speed of connection at a very low average delay throughout the United States, and with Canada and Cuba.

VIII. Conclusions, and Action Recommended

The International Telephone Committee, after consideration of the facts developed through its investigations of existing conditions, is satisfied that international telephony in Europe is in need of further improvement.

The Committee realizes that permanent improvement is, of necessity, an evolution. It is impressed with the progress already made in improving the international telephone service by the Administrations, particularly in view of the conditions which existed before the formation of the International Consultative Committee.

The work of that Committee deserves the support of the business men of Europe, who should urge upon their several Administrations the importance of international telephone communication, especially in view of its economic importance as noted in Section II of this report.

The International Telephone Committee realizes that the activities of the International Chamber should be constructive and cooperative, that its function is to express the requirements of the business men and that it should cooperate with existing administrative agencies in the attainment of sound objectives.

These objectives can be expressed very simply, they are:

> Uniform, dependable, fast service with good audition between all important trading centres in Europe.

The following resolutions were, therefore, submitted:

RESOLUTIONS PASSED

Resolution No. 18
of the
Stockholm Congress

INTERNATIONAL TELEPHONY

The Congress of the International Chamber of Commerce,

Recognizing that Telephony has been so much developed that satisfactory speech is practicable across Continents and further recognizing that efficient and speedy communication by speech tends to remove many impediments to the conduct of Trade and Industry, and,

Considering that, in spite of the great improvement effected through the efforts of the International Consultative Committee and the thorough studies it has conducted and is continuing, the service on the whole is still far from that required to satisfy the present day requirements of business,

Resolves that National Committees of the International Chamber of Commerce be again requested to interest themselves in this matter and urge upon their respective Telephone Administrations the importance of providing the facilities for communication essential to their share of International Trade, with due regard to practical limitations as to the speed at which an adequate service can be developed.

Resolution No. 19
of the
Stockholm Congress

COMMUNICATIONS

The Congress of the International Chamber of Commerce,

Recognizing that the International Chamber of Commerce represents the users both of "Transportation," which applies to the transfer of persons and goods, and of "Communications" which applies to the transfer of ideas,

Recommends:

1. That the Bureau at Headquarters known as "Transport" shall henceforth be entitled "Transport and Communications."
2. That under "Communications" there be set up Standing International Committees to consider the most effective methods by which the International Chamber of Commerce can promote usefully the development of the various elements of International Communication, viz.:

   Telephone Service, with and without wire,
   Telegraph Service, Cable and Radio,
   Postal Service.
3. That all National Committees be requested to form special Committees and in their selection of members to include a majority representation of users.
4. That the work of these Committees be guided by the following principles:
   - (*a*) The general requirements of the users of international communication in each country to be regularly investigated.
   - (*b*) The specific requirements of the principal industrial, commercial and agricultural activities to be investigated with the assistance of experts in each class of activity.
   - (*c*) The requirements as to the different classes of Communications and as to the scope of the services to be investigated.
   - (*d*) Technical questions as to the methods by which the requirements of the users shall be met to be excluded from consideration by the Committees.
   - (*e*) The Committees should endeavour to work in close collaboration with telephone, telegraph and postal administrations of the different countries and with international bodies interested.

Aerial Cable Across the Moerdijk Bridge—Holland

By E. WILLIAMS

European Engineering Department, Internitional Standard Electric Corporation

A TOLL cable forming part of the European Telephone Network has been installed recently between Rotterdam and Roosendaal, by the Dutch Administration. It consists of 45 quads, 19 of 1.8 mm. gauge and 26 of 1.23 mm. gauge, and it will provide direct cable communication between the north of Holland, including The Hague and Amsterdam, and countries south, including Belgium (Brussels) and France. A section of this cable involving special features in carrying out the work has been erected aerially across one of the sea inlets, known as the Hollandsche Diep, where it is spanned by the Moerdijk Bridge.

The position of the main cable is indicated by the sketch-map, Figure 1. The Moerdijk Bridge is situated about 10 kilometres south of the old city of Dordrecht. This bridge is of braced arch construction and is approximately 1.6 kilometres in length, consisting of fourteen spans, each of 105 metres, resting on stone piers. It was built between 1869 and 1872 and was at that time the longest single track railway bridge on the Continent. On the southern side of the bridge a swing portion provides two openings, each of 20 metres, to permit vessels having high masts to be navigated up or down stream. Figure 2 is a general view of the bridge from the north shore.

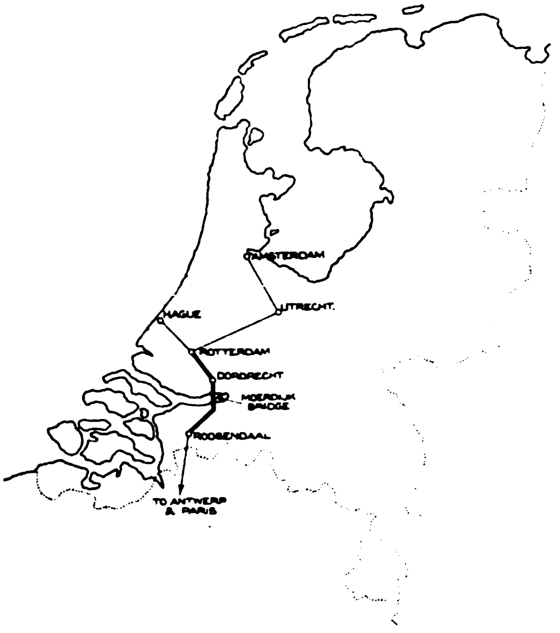


Figure 1—Map of Holland, showing the route of the Rotterdam-Roosendaal Cable and the aerial section across the Moerdijk Bridge

Each span is constructed with one end rigid and the other movable. Each shore-end is rigid and the two ends of the first and second spans, resting on the first pier, are free on rollers, while those on the second pier are both rigid and so on alternately across the stream. In addition to the expansion and contraction of the metal due to temperature changes, there is very considerable movement of the free ends on alternate piers, as well as some vibration at the centre of each span whenever a train passes. Observation at selected points has shown that the vibration may last for two minutes. A speed limit of 10 kilometres per hour has been set for all trains.

In 1923 an armoured cable was installed in steel tubing under the footway at the side of the railway track. Owing to the mechanical conditions of the bridgework, some trouble was experienced in maintenance at each of the free points on the piers. In 1925 the lead sheath was found to have crystalised at some of these points. This was due to vibratory movement caused by the trains, to provide flexibility and overcome the difficulty, loops of armoured cable were spliced into the cable and carried over rollers. The loops measure about 10 metres between rollers, and the sag is approximately 1 metre.

To avoid the possibility of troubles of the character mentioned, the Dutch Administration when designing the new cable, decided that the best type of construction to adopt was an aerial cable suspended on existing steel telephone standards clear of the bridge.

There are two open wire routes parallel to the bridge. One of these, i.e., that on the west side of the bridge, is a telephone route, the circuits being carried by double steel standards of angle iron, and the width between uprights being 2 metres. Four 1-inch tie rods are used to brace the standards to the masonry of each pier. The other route, which is on the east side of the bridge, consists of single steel standards that carry the railway telegraph circuits. Both of these routes are separate from the bridge spanning. The design approved provides for the suspension of the aerial cable with attachments to the inner uprights of the telephone standards at a distance of 4 feet from the bridge girders.

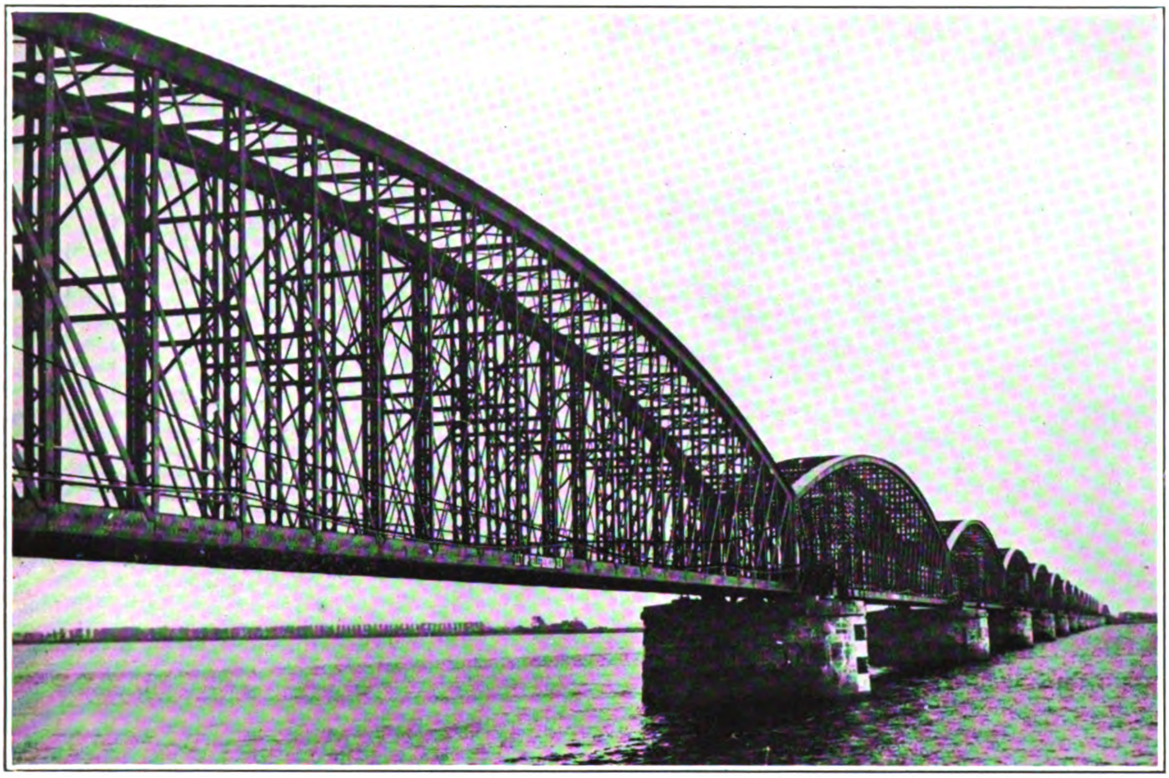


Figure 2—The Moerdijk Bridge, showing the aerial cable with suspensions in position

The plan, Figure 3, indicates the position of the aerial cable relatively to the bridge spanning.

In designing the suspension, two factors have had to be taken into account:

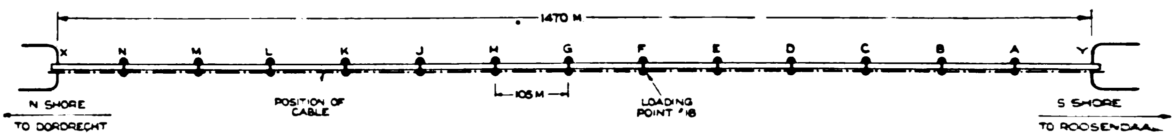
(1) The abnormal length of each span; viz., 105 metres (345 feet).

(2) The restriction which limits the extent of the dip permissible in the cable, on account of the very small amount of clearance which is given between the superstructure of passing vessels and the under side of the bridge girders. This clearance, at high tide levels, may be only a few inches, and for this reason the aerial cable-sags must be maintained within narrow limits at all temperatures and seasons of the year.

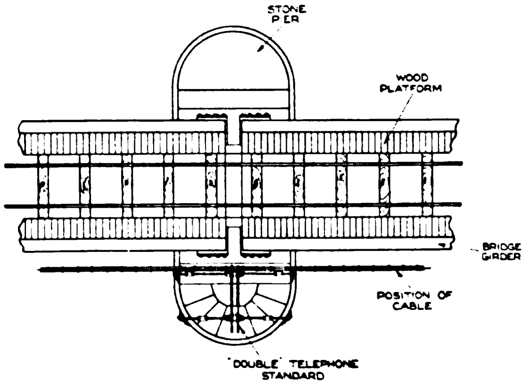
In order, therefore, to provide a suspension structure of the requisite strength and at the same time to meet these conditions, it was necessary to design a bi-suspension consisting of an upper supporting strand attached to a lower suspension by clamps at the centre and by suitable tie rods placed at the quarter spans. The lower suspension strand thus holds the rings and cable in four catenaries over each span.

The separation between the upper and lower strands on the steel standards is 3 metres. The suspension was designed so as approximately to equalise the load imposed by the cable between the upper and lower strands.

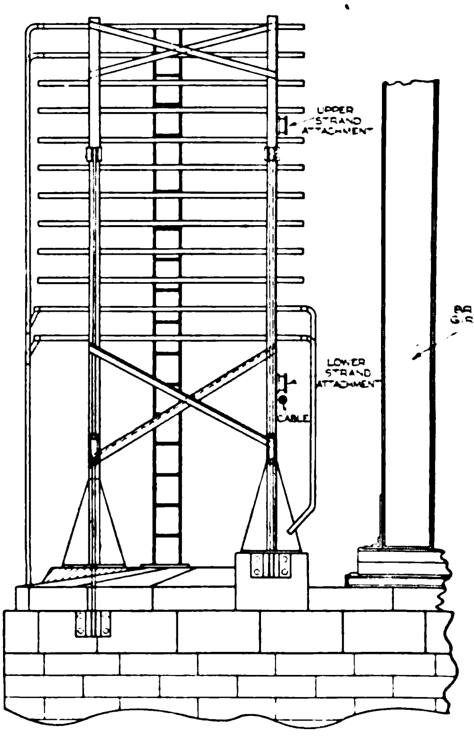
Tension and stretch charts were plotted, and from these the initial sags were calculated for both strands dividing the load; also, graphs were prepared giving the initial and ultimate tensions over the desired range of temperatures,



PLAN VIEW OF BRIDGE.



PLAN VIEW OF PIER.



VIEW OF A PIER SHOWING RELATIVE POSITIONS OF CABLE AND ATTACHMENTS.

Figure 3—Plan of Bridge, showing piers, span lengths and position of aerial cable

based on a factor of safety of 2.5. Figures 4-A and 4-B indicate in graph form the tension and sags actually obtained on each of the strands.

It was decided to terminate the upper guy strand by means of a dead-end or make-off on each alternate standard. In order to obtain a satisfactory and secure type of fitting for the purpose, a cast iron bollard having a drum diameter of 6 inches was designed. This was bolted to a 50 x 20 centimetre metal plate which was in turn attached to the angle-iron inner uprights of the standard by six bolts. Figure 5 illustrates this type of metal fitting and also shows the upper strand coming from either direction, terminated in each case with three guy clamps in the standard manner.

In the case of the intermediate through points, the attachment to the standard was made by means of a single cable-suspension clamp bolted to a smaller metal plate secured to the standard. This fitting is illustrated in Figure 9.

In the case of the lower strand, the number of through points was governed by the manufactured lengths which it was possible to obtain. Two lengths were erected each covering four spans with three intermediate attachments and

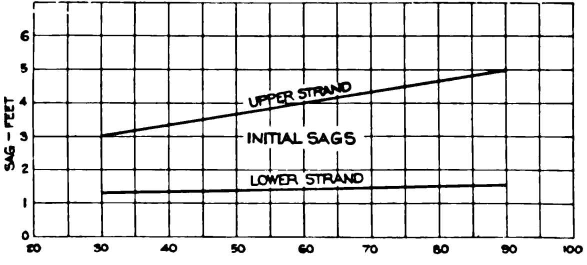


Figure 4-A—Sags—Upper and Lower Strands

two dead ends, and two each covering three spans with two intermediate attachments.

The strand was run out by means of hooks attached to the bridge and was hauled to position by a winch, placed on one of the bridge piers. It was drawn up to tension by a gang of five men with block and tackle. The sag desired for each span was sighted between the two standards by the aid of glasses, and when obtained the attachments were secured. The tension was then checked by oscillation tests.

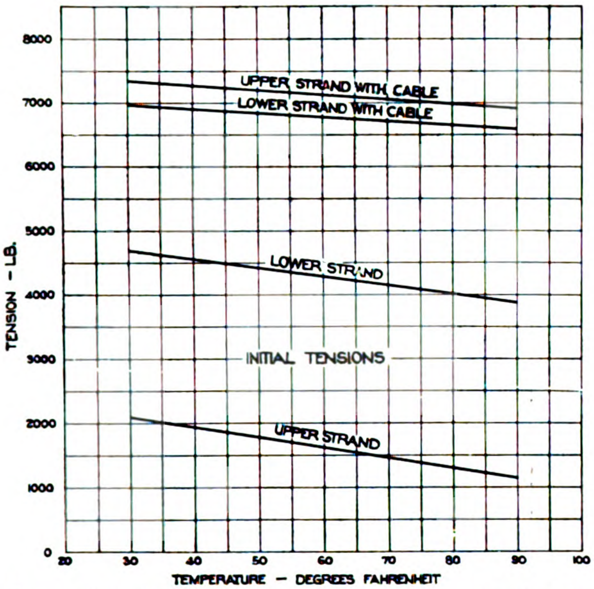


Figure 4-B—Tensions for Strands—With and Without the Cable Load

The following are the particulars of the two strands respectively:

The upper and lower strands were drawn together at the centre of each span by means of a special tool, and held by means of four clamps. A temporary portable staging attached to the bridge girders was used for giving the workman a foothold. Afterwards the tie-rods were placed on the quarter spans. At this stage the position of the centre clamps was 175 centimetres below the points of suspension of the upper guy strand, the lower strand forming an arch with the centre 125 centimetres above its suspension points.

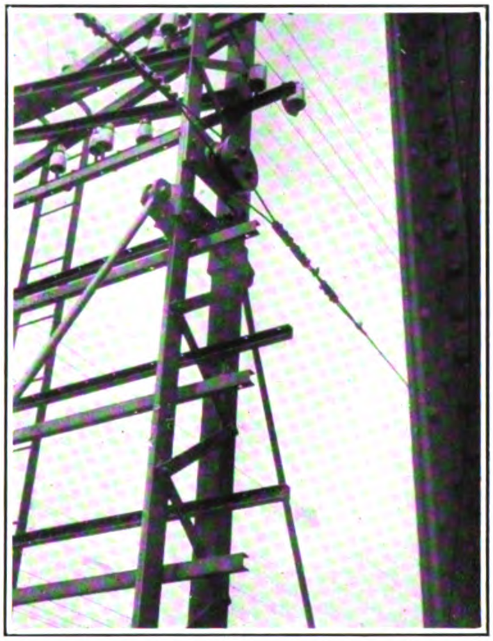


Figure 5—Telephone Standard on a Pier, showing cast iron bollard with upper strand terminated with three clamps on both spans

No. of Wires	Average Diameter Each Wire	No. of Spans	Length of Span	Mean Temp. When Erected (Degrees Fahr.)	Sag Allowed	Oscillations per Min.	Calculated Tension
(1) UPPER GUY STRAND							
7	0.142 ins. =(0.36 mm.)	14	344.5 ft. 105 metres	52	3 ft.–8 ins. =(1.118 M.)	32	1,850 lb. =(839 kg.)
(2) LOWER STRAND							
7	0.142 ins. =(0.36 mm.)	14	344.5 ft. 105 metres	48	1 ft.–3 ins. =(0.407 M.)	52	4,470 lb. =(2,028 kg.)

A laboratory test was made on a sample of the strand (16,000 lbs.). It showed a result of 8.82 tons (19,757 lbs.), an ultimate stress of 79.6 tons per square inch.

The placing of the rings and cable in position lowered the centre and tie rods to levels approximately in line with the points of suspension, the cable on each span remaining in the

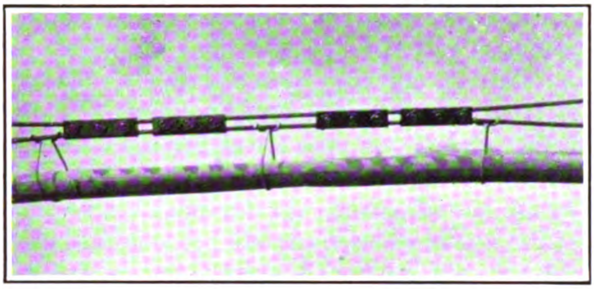


Figure 6—Centre Span Clamps

form of four catenaries 26.25 metres in length with sags approximating 30 centimetres.

It was possible to make oscillation tests on the first quarter of the upper guy strand after the cable had been erected, as the weight of the cable was sufficient to prevent the oscillations from extending beyond the tie rod position. From the readings obtained the tensions were calculated and these agreed approximately with the previous calculations as shown in the graphs. The load on each quarter span of the lower suspension also was calculated. The results showed that the object of dividing the load approximately equally between the two spans had been achieved.

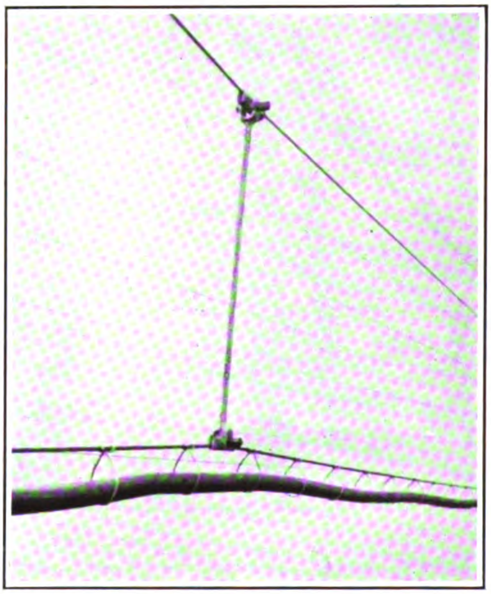


Figure 7—Quarter Span Tie Rod

The cable was drawn out in nine lengths, with a splice at each alternate standard except in the case of the loading point situated on Pier F.

The weight of the cable is approximately 7 lbs. (3.17 kg.) per foot, so that a load of about 21 hundredweights is borne on each span. Its diameter is 2.36 inches (60 mm.). A 3½ inch (8.9 cm.) "Bonite" type of ring, spaced at 16 inches (40.65 cm.) was used.

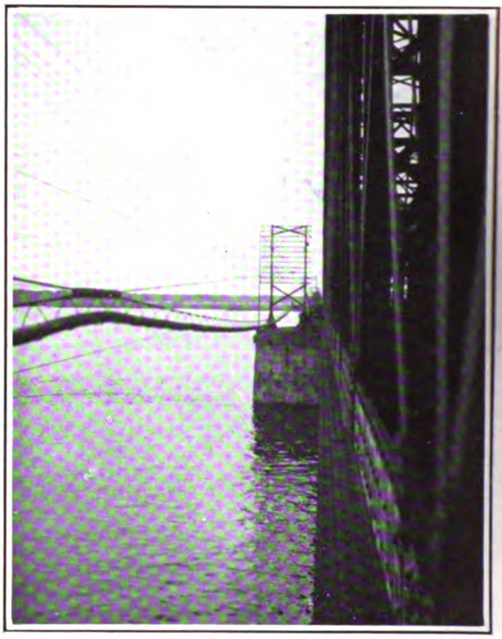


Figure 8—View of Cable from Centre of Span to Standard

Figures 6 and 7 show close views of the centre span attachment consisting of four 3-bolt clamps

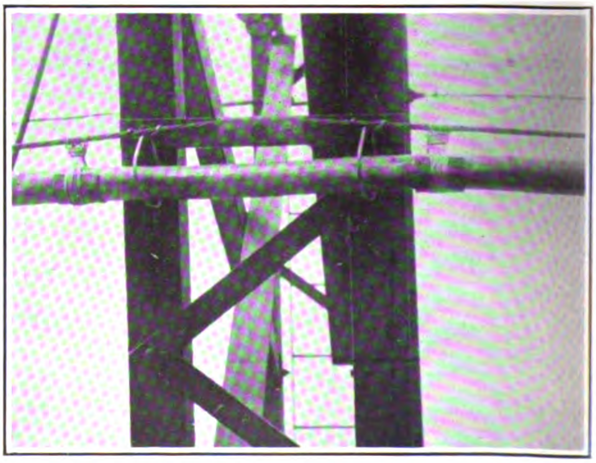


Figure 9—Cable Lifted from Rings by Wire Ties at a Through Strand Position

and the tie rod placed at the quarter span. Figure 8 is a view of the cable from the centre of the span to one of the standards.

Figure 9 depicts the cable carried through and lifted with ties at the point of attachment on one of the standards.

A cable joint on one of the piers is illustrated in Figure 10.

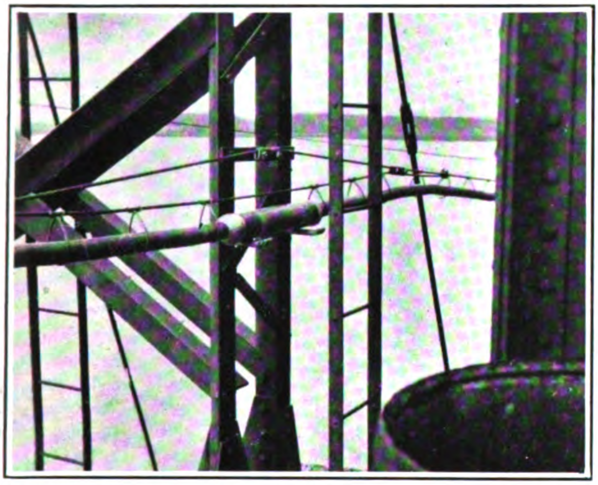


Figure 10—Cable Splice Resting on Brackets with the Cable Supported by an Auxiliary Strand

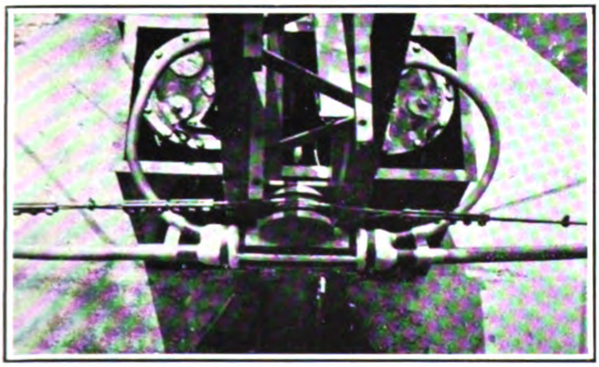


Figure 11—Loading Position, showing two loading coil pots placed in a metal tank and loading splice resting on brackets beneath a bollard holding the lower suspension strands

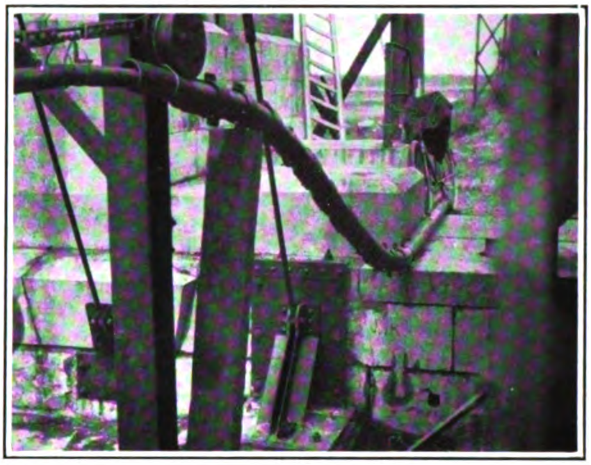


Figure 12—Method of Carrying the Cable Underground from the Shore Standard

A feature of interest is a loading point at one of the bridge piers, consisting of two pots of twenty-six and nineteen units, respectively. Figure 11 shows the loading pots in position.

The method of carrying the aerial cable from the shore standard to the ground and continuing it underground is illustrated in Figure 12. A short length of rubber hose was drawn over the cable extending from the standard to the ground, and a protective split flexible metal tubing was then placed over the hose. The section of cable laid underground is protected to the point where it is jointed to the armoured underground cable with Zores iron tubing.

During the period of installation, May and June of 1926, the day temperature varied between 40 degrees and 75 degrees Fahrenheit. Notwithstanding generally stormy weather and very severe conditions, the work was completed successfully. Installation was carried out by the Dutch Telegraph Administration with a gang of seven men. Testing, balancing and the loading of the cable was performed by Standard Telephones and Cables, Limited, London.

Train Despatching in Spain

By D. B. BAKER

Vice President, Standard Electrica S. A.

IN 1924, the last year for which the statistics are available, Spain had 15,473 kilometres of railway line, of which 11,684 kilometres was of standard broad gauge, 1.67 metres in width. Most of the lines of any length are standard broad gauge; the narrow gauge lines are almost in every case for local service only. Railway service in Spain is provided by ninety-three companies, made up of twenty-seven companies using standard broad gauge, and sixty-six companies using narrow gauge. Only a few of these companies are of more than local importance.

The most important lines are the Cia. de los Ferrocarriles de Madrid a Zaragoza y a Alicante (M.Z.A.),[1] Cia. de los Caminos de Hierro del Norte de Espana (Norte), Cia. de los Ferrocarriles Andaluces (Andalucian), Soc. de los Ferrocarriles de Madrid a Cáceres y a Portugal (M.C.P.).[2] These can be considered as representative of the railway business in Spain. Combined they constitute 80 per cent of broad gauge and 60.3 per cent of all broad and narrow gauge lines in existence in the country. The M.Z.A. have 3,663 kilometres, the Norte 3,581 kilometres, the Andalucian 1,307 kilometres and the M.C.P. (including the "Western" lines) 777 kilometres of broad gauge line. As regards traffic, in 1924 these four companies combined accounted for 86 per cent of passenger traffic over broad gauge lines and 51 per cent of all railway passenger traffic, 83.1 per cent of goods traffic over broad gauge lines and 61.2 per cent of all railway goods traffic.

During the last decade or so the Spanish railway traffic has considerably increased. This development is apparent from the curves (Figures 1 and 2) showing the increase of passenger traffic and goods traffic of the four principal railways of Spain. These figures are inclusive of 1924, the last year for which official figures are available. The passenger traffic of these four railways has grown steadily; it has been doubled since 1910, and in 1924 it was three times as great as in 1900. The M.Z.A. has doubled its passenger traffic during the last ten years and more than trebled it since 1900; the Norte Company has doubled its passenger traffic during the last fifteen years. These two companies account for 89 per cent of the total for the four leading companies.

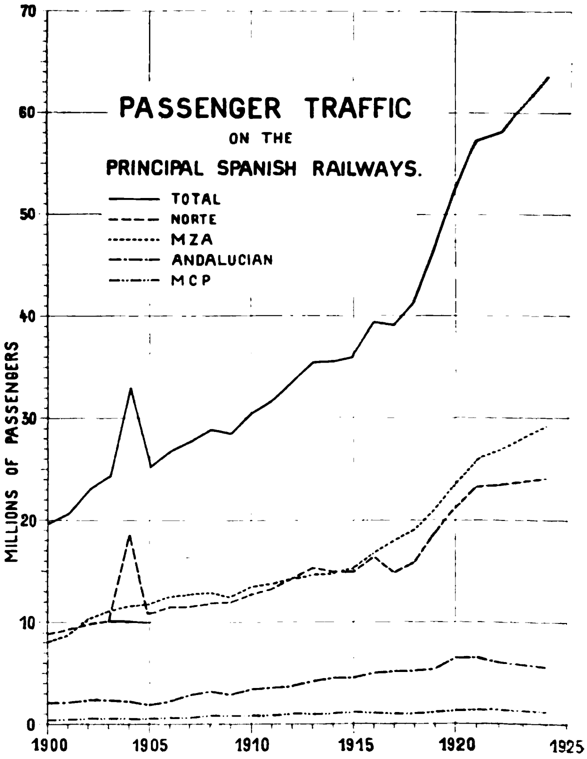


Figure 1—Passenger Traffic Chart

As regards goods traffic, the M.Z.A. and Norte again hold approximately equal positions. Combined they account for 87 per cent of the total of the four leading railways considered. The growth of goods traffic has been much slower than that of passenger traffic. During the last ten years goods traffic has increased only about 43 per cent; since 1900, it has doubled. Great fluctuation in goods traffic has taken place during the last ten or fifteen years, with three "boom" periods, 1912-13, 1916-19 and 1924, and two "slump" periods in 1914 and 1919. During the period of 1919-1922 the

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[1] Madrid—Zaragoza—Alicante.

[2] Madrid—Portugal.

M.Z.A. suffered more from economic depression than the Norte, and its goods traffic fell to about what it was in 1913. During the last two years it has fully recuperated, very considerable growth having taken place during this period.

The above figures show healthy and steady growth of railway business, necessitating the extension and modernisation of the operating methods in several directions. The necessity for modernisation is fully appreciated by the General Railway Council (Consejo Superior de Ferrocarriles) as indicated by the radical programme of reconstruction and extension of the railway system that was put in force recently, and by the fact that P.300,000,000[3] was voted for this work during 1926. Of this sum, P.130,000,000 was for rolling stock alone.

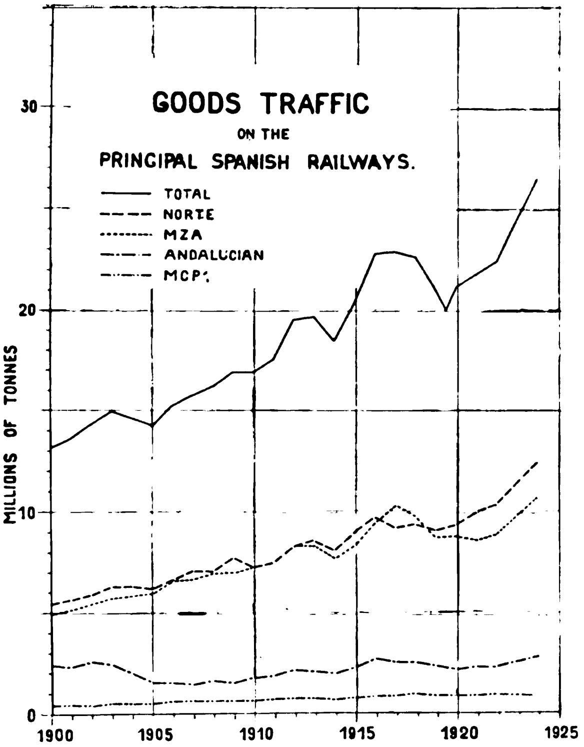

Figure 2—Goods Traffic Chart

Some of the improvements necessary were undertaken by the railway companies long before this grand programme of reconstruction was thought of, and the most important among these was the adoption by the leading railway companies of modern signaling systems.

Several years ago the railway companies found that the old fashioned telegraph signaling system was neither adequate nor efficient, nor was it satisfactory in its operation. The railway companies consequently investigated the various modern methods of signaling available. The outcome of this was that the Western Electric Train Despatching System was adopted by the two leading companies in Spain, the M.Z.A. and the Norte, and later also by the Ferrocarriles Catalanes, in preference to all other systems.

The verdict of the railway companies in favour of the Western Electric Train Despatching System was based on the fact that in their investigation they found that:

1. The Polarity System, a selective ringing system depending upon polarised and biased ringers for selection, did not allow of the inclusion of a sufficient number of stations.
2. The Harmonic System, a selective system with tuned reeds provided at each subset, each reed having a particular natural frequency, and signaling being effected by alternating currents of different frequencies, was too complicated, and required high technical training for the personnel.
3. The Selector System, a selective system in which the selectivity is obtained by some form of stepping mechanism—a definite number of direct current impulses of the same size being used for each station to be signaled—was untrustworthy inasmuch as the signals under certain line conditions did not arrive in proper form at the receiving station.
4. The Western Electric System using positive and negative impulses and condenser discharges to operate these selectors was more trustworthy and satisfactory in every way.

Fundamentally the Western Electric Train Despatching System is a selective-call omnibus telephone system, that is, all stations are connected parallel to a single pair of wires and the different stations are called by a series of positive and negative impulses which operate the selector at the called station without interfering with any other station. The heart of this system is the selector, a simple piece of apparatus consisting of an electromechanically operated stepping device, which permits the calling of any station without affecting the remaining stations. The operation of these selectors is controlled by the impulses sent out by the sending key at the despatcher office.

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[3] P=peseta. About 28 pesetas are at present equivalent to £1.

After the decision to adopt the Western Electric System was made, work of installation on the different lines was urged forward with considerable speed. The M.Z.A. Company ordered the first Train Despatching System in 1922 and in February, 1923, the system was in operation on certain important main lines. The Norte Company placed its first order for material in March, 1923.

The extent to which the Train Despatching System has been applied in Spain is apparent from the map, Figure 3. To the present moment the following systems have been installed or are being projected.

M. Z. A. Company
  Installed
    Madrid—Zaragoza
    Madrid—Alicante and Cartagena
    Barcelona—Zaragoza
    Barcelona—Port Bou
    Barcelona—Tarragona
    Barcelona—Empalme
      6 Despatcher Stations
      77 Way Stations
  In Process of Installation
    Madrid—Sevilla
      1 Despatcher Station
      16 Way Stations
  Projected
    Madrid—Badajoz
      1 Despatcher Station
      19 Way Stations

Norte Company
  Installed
    Madrid—Medina
    Madrid—Venta de Baños
    Venta de Baños—Leon
    Venta de Baños—Miranda
      4 Despatcher Stations
      90 Way Stations
  Projected
    Miranda—Irun
    Miranda—Barcelona

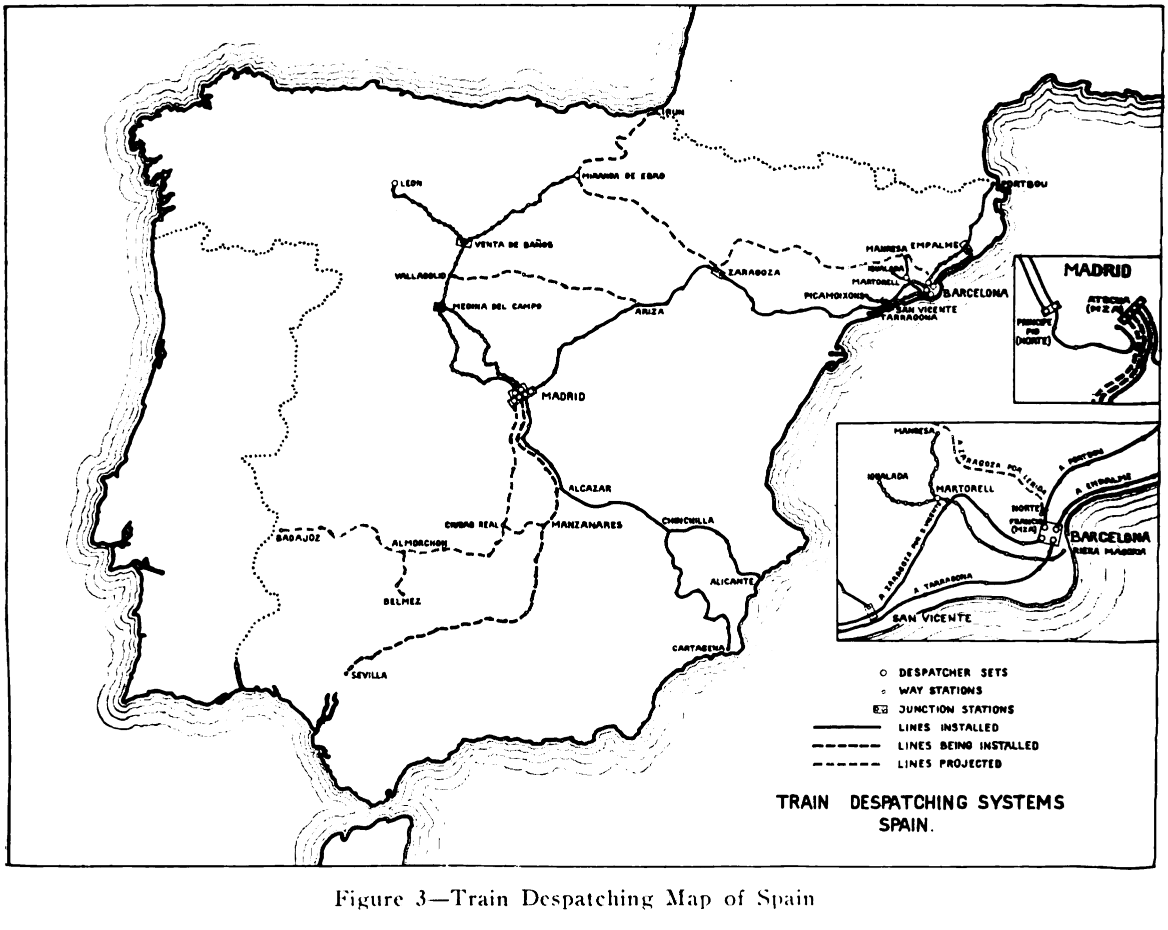


Figure 3—Train Despatching Map of Spain

F. C. Catalanes
Installed

Martorell—Barcelona Martorell—Manresa Martorell—Igualada	1 Despatcher Station, 28 Way Stations

The lengths of line equipped or to be furnished with Train Despatching Systems are as follows:

M. Z. A.	
Installed	1,641 Kilometres
In Process of Installation	574 Kilometres
Projected	830 Kilometres
Norte	
Installed	781 Kilometres
Projected	785 Kilometres
F. C. Catalanes	
Installed	102 Kilometres

The total length of line on which the Train Despatching System is at present in operation is 2,524 kilometres or 21.6 per cent of the total broad gauge railway in Spain; installed and in process of installation, 3,098 kilometres or 26.5 per cent; installed in process of installation and projected, 4,719 kilometres or 41 per cent.

The line from Madrid to Sevilla is at present being installed and the line from Madrid to the Portuguese Frontier is projected. The Norte Company also propose an extension from Miranda to Irun on the French Frontier and to Barcelona from Miranda via Zaragoza and Lerida.

In Spain, Train Despatching Systems are not used for controlling train traffic as for instance in the United States, but for information service. The Train Despatchers in Spain do not give orders to the Station Masters; they only give information and advice which the Station Master uses according to his best judgment. The Spanish Station Masters welcomed the Train Despatching System because by its means they have at their disposal the fullest and latest information about all traffic and other services and they can control and make up trains at their own stations with much greater facility and satisfaction. Perhaps the greatest assistance was in respect to the making up of goods trains.

In Spain also, way stations are not installed at every station, but only at the more important points, such as sorting, make-up, foot of incline and junction stations, locomotive sheds and inspection or control centres.

The experience of the Railway Companies already obtained, is such that they propose ultimately to extend the system of signaling to all their lines.

M. Z. A. Railway

The Train Despatching System as installed on the M.Z.A. Railway is shown in Figure 4. The first installations, as previously mentioned, were opened in February, 1923, and additional systems are being ordered from time to time, the policy of the Company being to install them on all their lines. A complete change-over from the old signaling system is not proposed, for the simple reason that such a radical change would dislocate the service and there would be no time to instruct the staff in the use of this new method of signaling.

On the M.Z.A. Railway, at present, three types of stations are used; namely, despatcher station, junction station and way station. The railway net is divided into several sections, each one of which is provided with a despatcher station and a certain number of way stations. End stations of each section are provided with the necessary apparatus to make them junction stations. These junction stations render possible the connection between the despatcher station and way stations of one section with those of another.

Some of the more important despatcher stations are provided with a cordless local battery switchboard by means of which different important officers and departments of the Railway Companies can be connected to the Despatching System. These cordless switchboards are at present installed at Barcelona and Madrid. They are provided with circuit facility for four train Despatching Systems and fifteen local lines, and a test line by means of which daily tests can be carried out. The microphone battery used is 6 volts.

Apart from the standard equipment there is also a considerable number of portable sets in use, chiefly by the permanent way staff.

The line construction is of the M.Z.A. standard open wire type employing hard drawn copper conductors varying from 2.5 to 4 millimetres in diameter.

Madrid—Sevilla Line Madrid—Barcelona Line	4 Millimetres

Madrid—Alicante	3½ Millimetres
Madrid—Cartagena	
Madrid—Badajoz	
Barcelona—Tarragona	3 Millimetres
Barcelona—Empalme (Mataro)	
Barcelona—Port Bou	2½ Millimetres

Attenuation of these lines is within the permissible limit for this type of circuit. The line from Madrid to Port Bou, the longest, has a theoretical attenuation of B = 2 or 17.4 TU under wet weather conditions.

The insulators used are of Spanish make and are of good quality. The open wire lines are transposed every 500 metres using rotating transposition in clockwise direction.

The method for taking the lines through the tunnels was carefully investigated. It was decided not to use open wire lines over the hills but to install cables. On the M.Z.A. railway on the section on which Train Despatching has been installed there are one hundred and sixty-two tunnels of a total length of 50 kilometres. In all these tunnels cables have been installed. The cable is air spaced paper insulation, armoured and lead covered. The characteristics of the cable are as follows:

> 3-pair cable, having 2 millimetre conductors, capacity 0.067 mfd. per kilometre, resistance 11.5 ohms per kilometre, insulation resistance 65,000 megohms per kilometre.

The cables are suspended from the walls of the tunnels and are connected to the aerial line by means of terminal boxes provided with protective apparatus (Figure 8). The protection of these cables was most carefully studied and that finally adopted is efficient and robust. The protective gear is placed at the mouth of the tunnels so as to be easily accessible, and is designed to protect the cable against lightning, static charges and direct induction.

An inductance with closed magnetic circuit is connected on one side to the cable and on the other to the open wire line. On the line side a spark-gap lightning arrester is bridged to ground and adjusted so as to break down at 1,000 volts or half the voltage at which the cable is tested.

At 250 metres from the tunnel another inductance is placed in series with the line, each side being connected to earth through a spark-gap protector. The position of the inductance is arranged so that the frequency of the free oscillations of the circuit is sufficiently high to prevent the passage of the oscillations through the inductance.

The apparatus and the lines are carefully maintained and for this purpose definite rules have been laid down for routine testing. The tests prescribed are as follows:

1. The resistance and insulation of the lines are measured every day. Breaks, short circuits and earth are located in the usual manner using a Western Electric Testing Cabinet.
2. Every five days the main battery voltage and local battery voltages are read. This test is carried out when normal current is carried by the line. For each installation the initial voltage of the battery is determined according to the length of line. The local battery voltage must be approximately 10 volts and never less than 7½ volts. When accumulators are used, the minimum voltage is 9 volts.

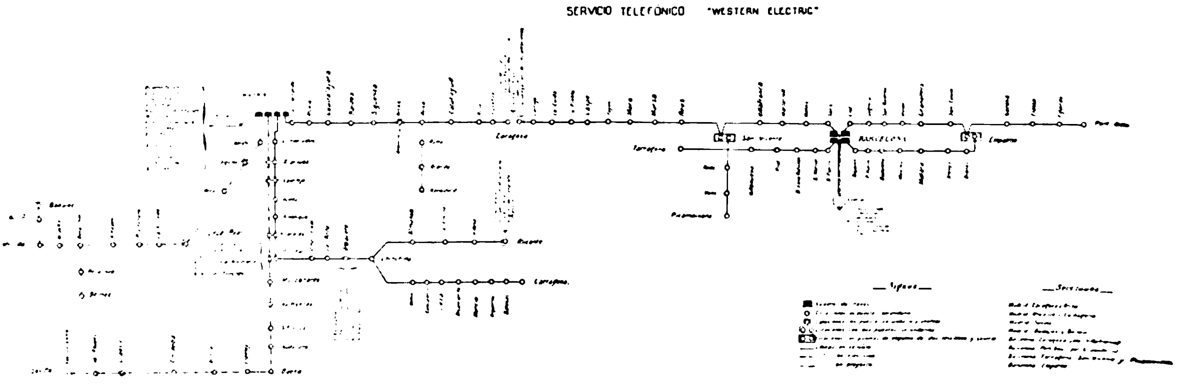


Figure 4—Train Despatching System, Madrid-Zaragoza-Alicante Railway (M.Z.A.)

3. Every month each calling key is tested to see that the duration of the positive impulses is the same as that of the negative impulses.
4. Every month all keys are tested to see whether the time taken to return to normal is correct. For 60-A keys this time is 7½ to 8 seconds.
5. Before the installation is put in operation and every three months thereafter a general test is carried out. This consists in reducing the main battery voltage by 30 per cent and calling each station successively.

As regards the routine tests of the lines, actual limiting values are prescribed for each circuit.

The Barcelona Despatcher Station is the largest in existence in Spain. From the Barcelona Despatcher Station four systems radiate, namely:

Barcelona—Zaragoza, via Villafranca
Barcelona—Tarragona
Barcelona—Port Bou, via Granollers
Barcelona—Empalme, via Mataro

The equipment of this station consequently consists of four Despatcher Sets, one for each of the sections, and also a special cordless switchboard which connects certain important officers and departments of the Railway Company to the Train Despatching Systems. A general view of the Barcelona Despatcher Station is shown in Figure 5.

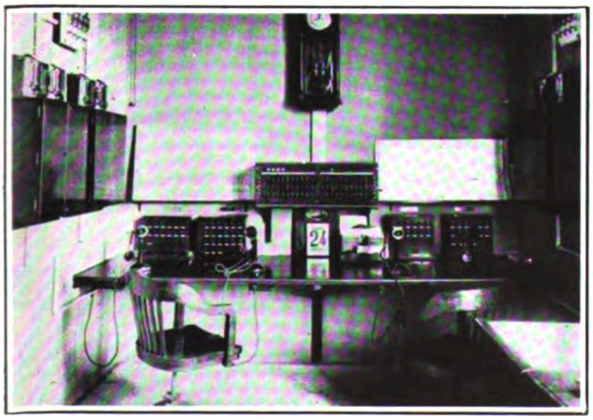


Figure 5—Barcelona Despatching Station, Madrid-Zaragoza-Alicante Railway

The Madrid Despatcher Station will have four Despatcher Sets. Of these, two are at present in operation; one is being installed; and the fourth will be added when the Madrid-Badajoz line is installed. The lines actually in operation are: Madrid-Zaragoza, Madrid-Alicante and Cartagena (Figure 4). At this station also there is the special cordless switchboard.

A way station which also serves as a junction station, is illustrated in Figure 6. An ordinary way station is illustrated in Figure 7.

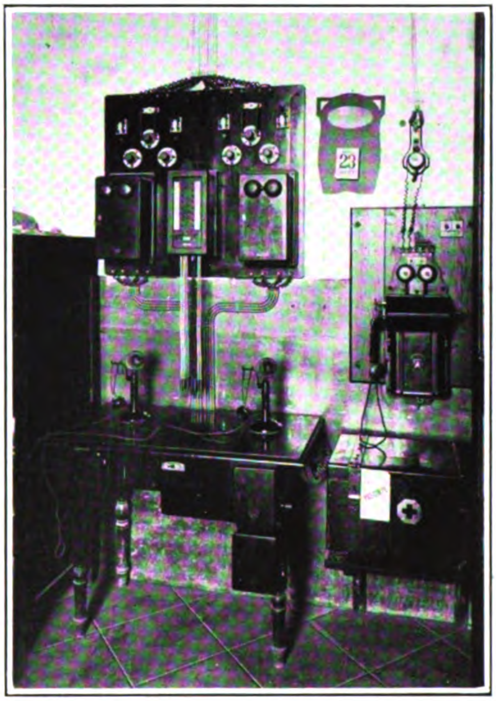


Figure 6—Junction Station, Madrid-Zaragoza-Alicante Railway

Norte Railway

The Norte Railway has had Train Despatching Systems installed for about three years and has found them most satisfactory and useful, so much so that at the present moment studies are in hand for the extension of the system from Miranda to Irun on the French Frontier, and to Barcelona via Zaragoza and Lerida. At Miranda, owing to the length of open wire line, which is of 3 millimetre hard drawn copper, and the number of way stations connected, the attenuation limit is very nearly reached. Consequently for this extension special studies have had to be undertaken.

The present installation of the Train Despatching System on the Norte Railway is indicated in Figure 9. A despatcher station is shown in Figure 10.

There are at present four sections installed: one from Madrid to Medina via Segovia, one from Madrid to Venta de Baños via Avila, one from Venta de Baños to Leon and another from Venta de Baños to Miranda.

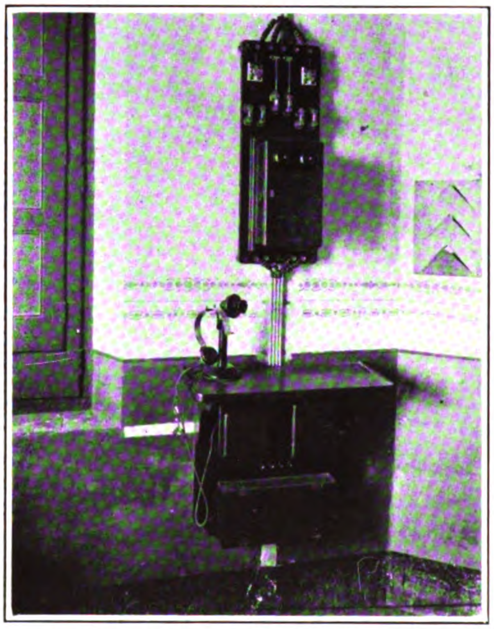


Figure 7—Way Station, Madrid-Zaragoza-Alicante Railway

Switches are provided at Madrid and Medina to connect the Venta de Baños line to Madrid via Segovia when the Avila line is out of order. Leon and Miranda are at present terminal stations and each have a Despatcher Set. The whole installation of the Norte Railway consists of four Despatcher Sets and ninety-one way stations.

At Venta de Baños there is a four line switchboard and a changeover switch. This station has three selectors—one each for the Madrid, Miranda and Leon lines—and by their means Madrid can be connected either to Miranda or Leon, or the Miranda and Leon lines can be interconnected.

The line construction is open wire of 3 millimetre hard drawn copper conductors, having a resistance of 2.5 ohms per kilometre. The line is transposed.

The maintenance of open wire lines is carefully organised and there are maintenance centres at the following places: Madrid, Villalba, Navalperal, Sanchidrián, Cercedilla, Neva de la Asunción, Medina, Valladolid, Venta de Baños, Quintana del Puente, Burgos, Pancorbo, Cisneros and Santas Martas.

The line men are required to report twice daily, once when they start out and once when they finish working. These reports are made to the Despatcher regardless of whether the lines are in perfect order or not. The line man also states his location so that in case of necessity he can be communicated with.

The apparatus maintenance is also very carefully organised and apparatus maintenance staffs are located at Madrid, Avila, Valladolid, Miranda and Leon. The maintenance men located at Madrid, Leon and Miranda, must visit the offices at least twice daily to see how the apparatus works, and when away from headquarters, they must always advise the Despatcher of their location so that they can be communicated with in case of emergency. When traveling they must look out for faults on the

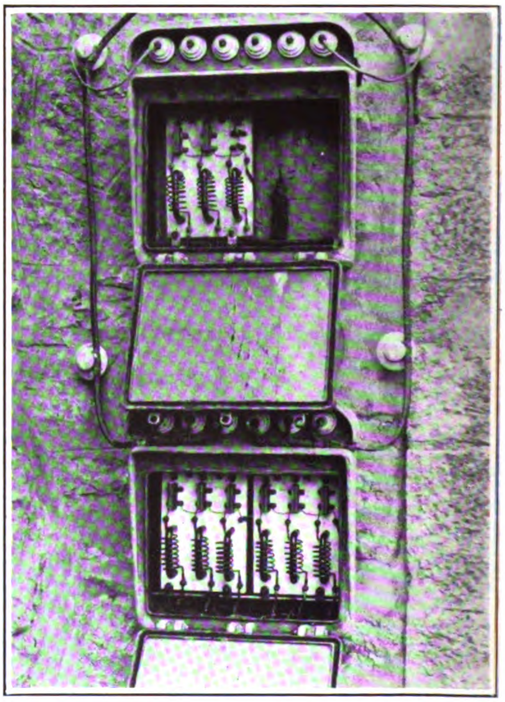


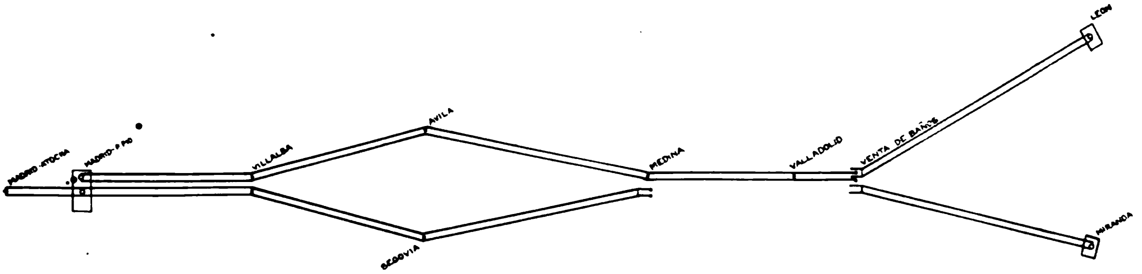
Figure 8—Cable Terminal and Protector Box, Madrid-Zaragoza-Alicante Railway

open wire and give orders to the line men as to how the faults are to be located and rectified.

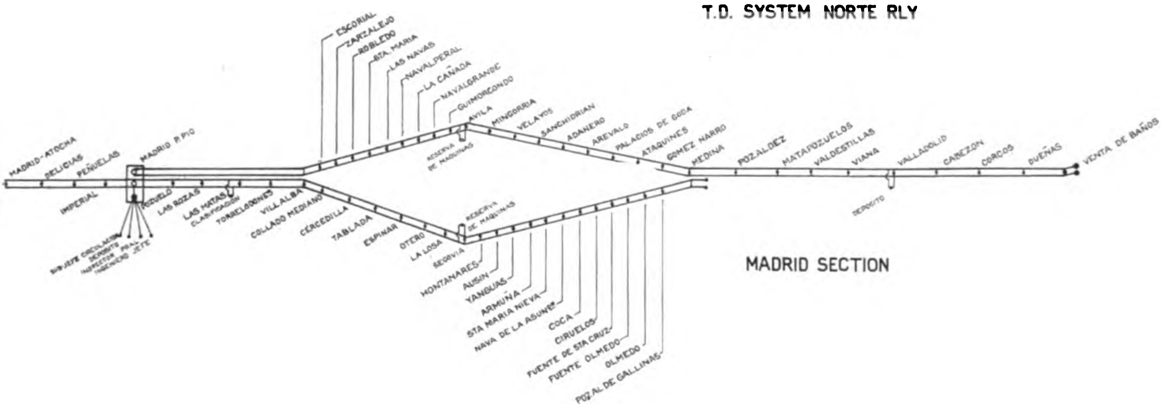
The maintenance of the selectors and other apparatus is carried out in accordance with special instructions. The Despatchers work in shifts of eight hours each, and each Despatcher has one telephone operator who is continuously listening-in on the line and who passes out orders as directed by the Despatcher. At Madrid, as there are two distinct lines going out, there are two telephone operators. At some stations, instead of headsets, loud speakers are used.

The Despatchers are under the orders of the Servicio Central de Explotacion (Operating Department) and in case of emergency the Inspector Principal de Demarcaciones personally gives the necessary orders. The business of the Despatchers is to know all the traffic conditions of their corresponding sections so that the best possible traffic developments may be obtained. The Despatcher communicates with stations giving information, advice and warning, and the Station Masters then act on their best judgment. The Train Despatching System can be used also to transmit very urgent messages.

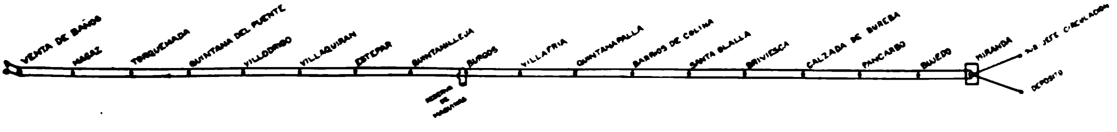
Normally, the circuits from Madrid, Leon and Miranda, terminate at Venta de Baños. If any Despatcher desires to communicate with a station beyond Venta de Baños, the operator



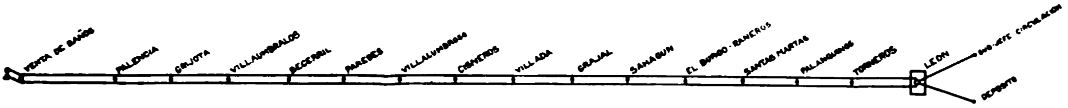
T.D. SYSTEM NORTE RLY



MADRID SECTION



MIRANDA SECTION



LEON SECTION

Figure 9—Train Despatching System, Norte Railway

at this latter place connects the circuit through so that the required station is in direct communication with either Madrid, Leon or Miranda as the case may be. As soon as the call is finished the operator at Venta de Baños disconnects the circuit.

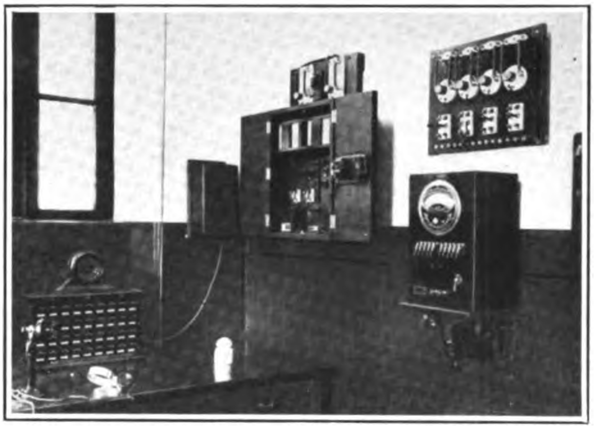


Figure 10—Despatcher Station, Norte Railway, Madrid

The Train Despatchers on the Norte Railway have to fill out different types of forms to record all movements and other information. The three most important forms used are Control of Train Movement, Locomotive Requirements and Goods Despatch. On the form of Control of Train Movement, entries are made of the arrival and departure of all trains at all stations of the section. The causes of delay are indicated on the back of the form. The forms for Locomotive Requirements are used to indicate the make-up of train, the number of trucks and tonnage and also the number of locomotives used to pull the train. In these entries are indicated also the goods yards where the trains are made up and the foot of incline where additional locomotives are required.

Goods Despatch forms are used to indicate the number of wagons loaded and empty that are ready for despatch at 7 o'clock in the morning at the station indicated. All stations provided with Train Despatching telephones must report the arrival and departure of all trains to the Despatcher.

Ferrocarriles Catalanes

This is a narrow gauge, one metre, railway, which provides service between Barcelona and Igualada and Manresa. It has one despatcher station and twenty-eight way stations. In the despatcher station of this railway a three-key box is installed by means of which one, two or all three of the lines arriving at the despatcher station, Martorell, can be disconnected and switched to an extension bell so that continuous listening-in is not necessary. This extension bell is provided with a small central battery, and each way station is provided with a push button which when operated rings this bell, and advises the Despatcher that a station is calling.

For further particulars of traffic control apparatus, including applications to train despatching and tramway service control, reference may be made to:

"Telephone Traffic Control for Tramways," "ELECTRICAL COMMUNICATION," Vol. 2, No. 2, October, 1923, p. 141.

"Telephone Train Control in the Argentine Republic," C. F. Bulstrode Whitlock, "ELECTRICAL COMMUNICATION," Vol. 4, No. 4, April, 1926, p. 253.

"Modern Methods in Train Dispatching," "ELECTRICAL COMMUNICATION," Vol. 3, No. 1, July, 1924, p. 57.

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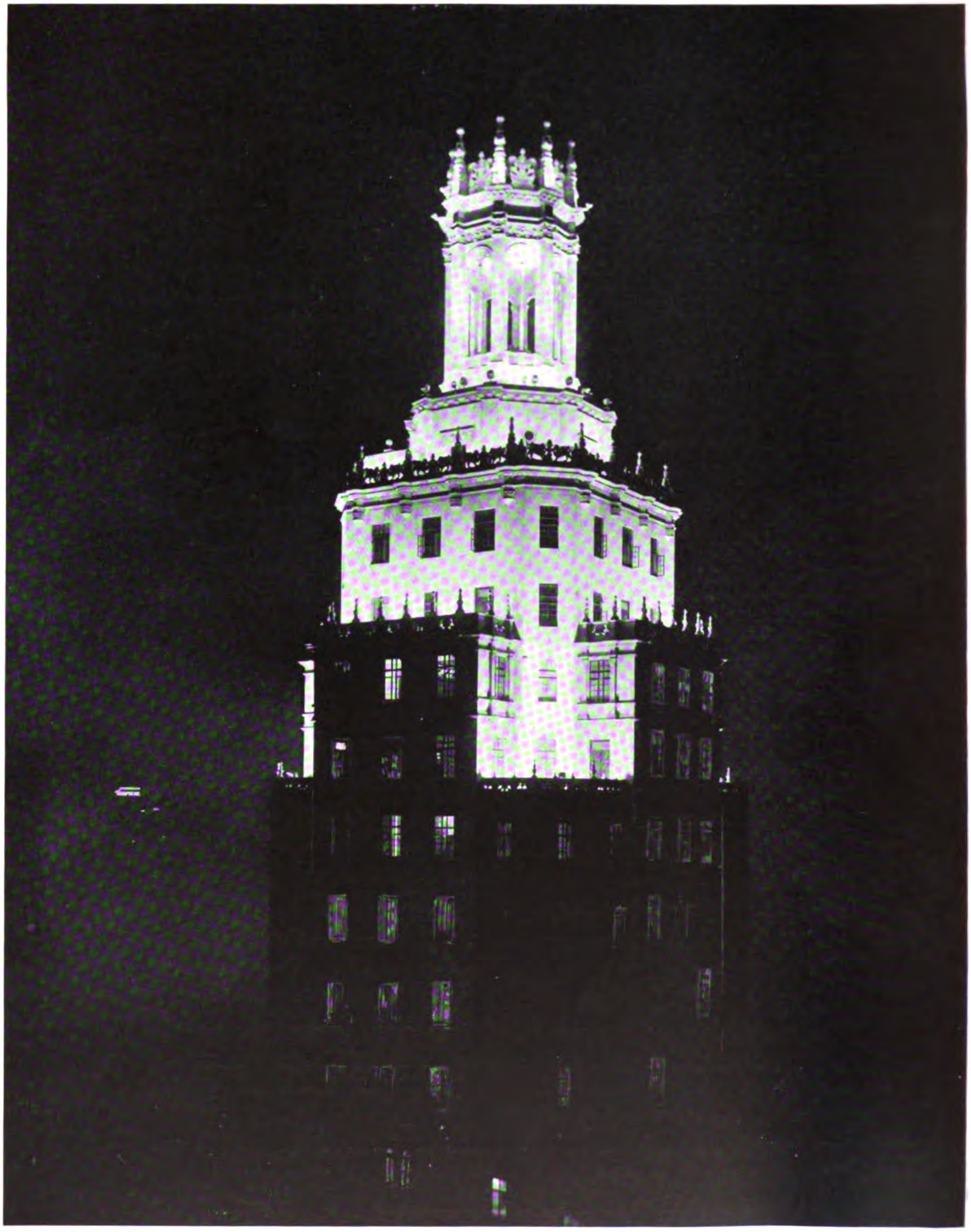

New Building of the Cuban Telephone Company, Havana. It is the highest building in Cuba, consisting of ten stories and a three-story tower. The illustration shows the results of the recent installation of floodlighting equipment.

The Volta Centenary Exhibition at Como

MAY TO OCTOBER, 1927

THE object of this exhibition cannot be better stated than in the words of the invitation of the Executive Official Committee:

> Alessandro Volta, by his marvelous invention of the voltaic cell rendered possible telephony and telegraphy. These are foremost amongst the applications of electricity to the practical problems of civilisation. To recall his achievements, it was thought appropriate to regard telegraphy and telephony as a symbol, and to promote at Como an International Exhibition and an International Technical and Scientific Congress relating to them and to radio. We therefore invite all public and private telephone administrations, all manufacturers of apparatus and telegraph and telephone material, and all persons interested in the problems of telegraphy, telephony, and radio to participate in the Exhibition and at the Congresses.

The historic Villa del'Olmo (Figure 1), that recently became the property of the Como Council, was utilised for the Exhibition. It is situated about a mile from Como, at the edge of the lake. With its large park and spacious pavilions it admirably served its purpose.

The Exhibition was formally opened on May 28, 1927, by H. M. the King of Italy. The operating administrations or companies, giving telegraph and telephone service in different countries, exhibited representative items in the Villa del'Olmo itself. Manufacturers' exhibits were located in the new pavilions on the left of the Villa. Professor di Pirro, Director General of the Istituto Sperimentale of the Italian Post, Telegraphs and Telephones, was responsible for the organisation of the first group. Mr. Comboni, Secretary of the Italian Electrotechnical Association, organised the second group. There was also an exhibit to convey an idea of the development of hydro-electricity in Italy and another of silk material and silk-weaving machinery.

The exhibits (Figure 2) of the International Standard Electric Corporation and the Standard Elettrica Italiana, its Italian Associated Company, located in the largest pavilion, were intended to show the various aspects of electrical communication. The outside plant exhibit included underground and open-wire lines installed in the park. The underground exhibit demonstrated the method of laying a cable into a trench from a cable reel trailer, and the arrangements for jointing, pressure testing, mechanical protection and bonding.

A loading coil manhole, of countersunk type, had a base of concrete, supporting two concrete cylinders containing the bodies of the loading pots. The sides and ends were of concrete and the top was made of removable slabs of reinforced concrete, so that the cable joint was easily accessible. One of the loading pots was jointed to the main cable. The second pot was in position, ready to be jointed.

Another method of protecting the joints, especially for non-armoured cables laid in ducts, was illustrated, in which two cable joints were protected by means of a collapsible concrete box. The base and the ends of the box were in one piece. The sides and the lid could be removed to give enough space when working on the joint.

Toll and exchange cables, including an armoured cable and a leading-in cable from an aerial route, entered a manhole from different sides and through a glazed earthenware duct, thus indicating the manner in which it could be led into the basement of an exchange.

The aerial exhibit showed how a underground cable may be extended from a terminal pole of an aerial route. An insulating joint separated the underground and aerial sheaths to prevent stray currents from passing to or from the underground system. The steel strand was of suitable strength for the suspension of the heaviest type of telephone cable manufactured. The loading of an aerial cable was illustrated by an H-pole structure, carrying two loading pots supported by brackets and girders. Provision was made also for the two additional pots to be placed subsequently. On the next pole, the toll cable was terminated through fuses and lightning arresters contained in a No. 18 type cable terminal, and from this point the toll circuits were continued by ten pairs of open-wire toll-lines, suitably transposed. In the same span, a subscriber's aerial cable was erected. Half of this was terminated on the next pole through carbon arresters and a "B" type cable terminal. Some of the remaining circuits were taken underground; the others were carried over the last span in a small aerial cable and ended in a C-type terminal.

Figure 1—The Villa del'Olmo.

The repeater exhibit, Figure 3, displayed specimens of the various types of bays placed in one row. From left to right they were: the No. 5 Toll Testboard, the repeating coils and networks, the 20-cycle ringers, the voice frequency ringers, the 4-wire terminating sets, the 2-wire and 4-wire repeaters, and the testing and supply apparatus.

The No. 5 Toll Testboard employs the ordinary iron racks used for repeater mounting, in place of the switchboard type used heretofore. This testboard is used in repeater and terminal stations for making maintenance measurements on the lines and apparatus, and for making temporary connections between the lines and apparatus to meet emergencies. A voltmeter position and a Wheatstone Bridge position were exhibited and part of the jack field was wired to the apparatus on the other racks. The next three bays contained the repeating coils used to obtain the proper impedance ratio between the line circuits and the repeater or office equipment, also the balancing networks for 2-wire repeaters and the low frequency correctors for 4-wire repeaters. The first bay on the left was for the 2-wire circuits, while the two bays on the right were for the 4-wire circuits.

The repeater rack itself consisted of five bays. The first from the left included the 20 to 20 ~ through ringer panels, the second the voice-frequency ringer panels, and their test panel, while at the bottom were the terminating sets for the 4-wire circuits. The third and fourth bay included respectively the 2-wire and 4-wire repeaters, the latter being used for long circuits. The last bay on the right carried echo suppressors and their test panel. The echo suppressor is designed to eliminate the echo currents coming back on a long 4-wire circuit.

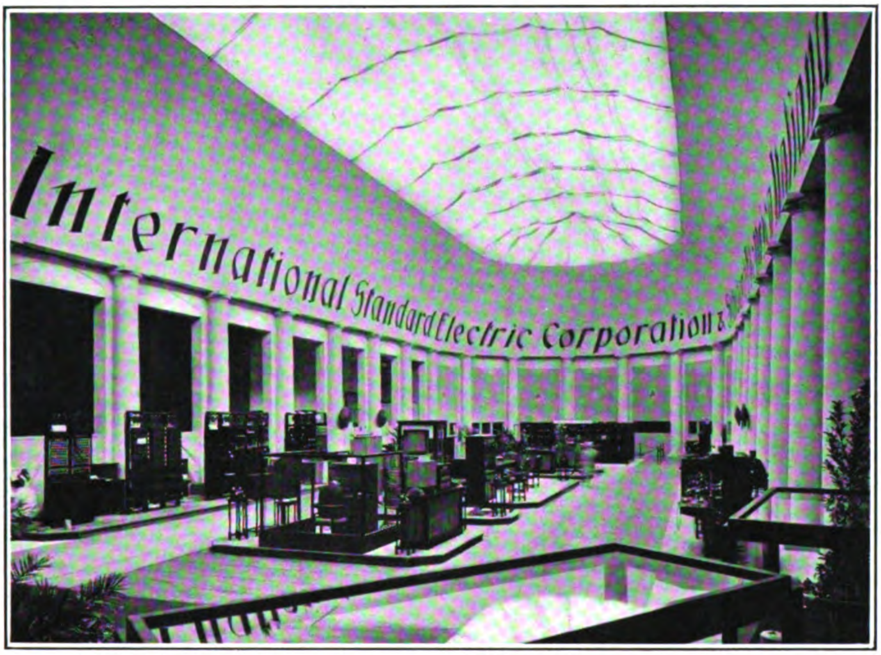

Figure 2—Exhibit of the International Standard Electric Corporation and Its Associated Company, Standard Elettrica Italiana.

The last rack consisted of four bays of testing and control apparatus. On the left was a transmission measuring set, capable of measuring transmission line levels and losses, repeater gains or apparatus losses. The second bay included a variable frequency oscillator, having a range of 35 to 50,000 cycles per second and its special amplifier, for the supply of amplified testing frequencies.

The third bay carried the meter panels for measuring currents in the filament and plate circuits, a filament control panel for making valve rejection tests, and a key panel. The last bay on the right contained the fuse panels and the plate (circuit and 20 ~ ringing supply) protection lamps. A small rack, erected behind the main exhibit held a generator giving the voice frequency ringing current, at 500 cycles magnetically interrupted at 20 cycles.

The exhibit of automatic switching machines consisted of various types of automatic private branch exchanges. The telephone service in the whole exhibition was given by a No. 7000 P.B.X., with its associated attendant's board to establish and record the toll calls.

The second part of the automatic exhibit was a demonstration of the Rotary System for large city areas, showing the way in which a call is established through the interconnected offices. Though there were only five lines completely equipped, every particular case, such as "busy line" and "non-completed call," could be shown and demonstrated.

The third part consisted of a certain number of small automatic P.B.X's of the step-by-step type. On each side of the No. 7000 automatic switchboard was a No. 7001 P.B.X., the capacity of which was 35 lines.

In order that the visitors might get an idea of the different kinds of manual switchboards used in urban and toll telephony, some typical specimens were exhibited. The first on the right consisted of two positions of a No. 1 Toll Board, and an associated cord circuit repeater. Every line which can be used with this repeater has a balancing network and the operator has a device to put them in circuit and to control the gain.

One of the principal exhibits was the broadcasting station, complete with its studio, control, and machine rooms. The radio transmitter was capable of delivering 5 KW. to the antenna system, and it operated on a wave-length of 500 metres. It is similar to that of Prague, except that the speech input equipment and oscillator modulator unit have been modified.[1]

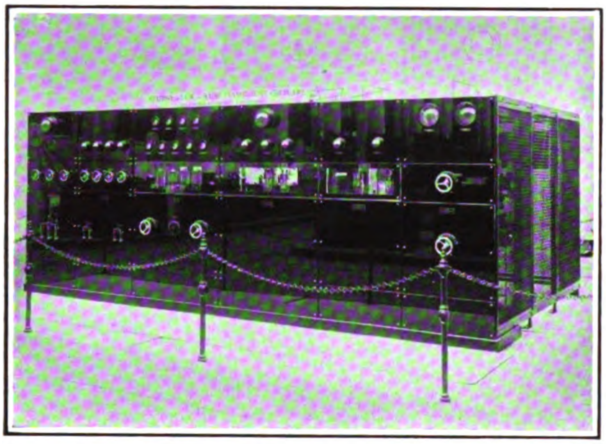

Figure 3—Repeater Exhibit of the International Standard Electric Corporation.

Two forms of microphone were used; i.e., the condenser type and the double-button carbon instrument. Adjacent to the studio was the control room, which contained the speech input equipment and a power switchboard at the back.

The radio transmitter itself (Figure 4) was of recent type, in which the carrier current is generated at very low power level. Modulation also is performed at low level, subsequent multi-stage high frequency amplification giving the power required for feeding the antenna. This arrangement results in high quality modulation and it has other important advantages.

A No. 1 Public Address System was used for distributing speeches and music. The connections were such that, if desired, the System could be operated from the microphone and the speech input equipment used in broadcasting.

The loud speakers were arranged in four groups, giving different kinds of service. Some of the projectors were set in a direction to send speech and music over the lake and to the other bank, east of Como. The broadcasting station and Public Address System were used regularly and they relayed daily the orchestra of the Villa d'Este; another orchestra also played nearly every day in the studio.

The Public Address System was used during the Italian and International Regattas, on the Lake of Como. A small radio transmitter was installed in a motor-boat, while the receiving set in the studio transmitted directly the results, through the Public Address System, to the thousands of people crowded over the Exhibition ground.

In September, when numerous congresses were held in Como, the broadcasting station and the Public Address System were used to relay the principal speeches delivered in the Villa del'Olmo, the Social Theatre or the Carducci Institute of Como.

Apart from the testing apparatus shown in the repeater exhibit, specimens of portable sets were exhibited; i.e., a transmission measuring set, a crosstalk measuring set, a capacity unbalance set and several artificial lines. The oscillators used to provide the testing current for these sets included small vibrators as well as vacuum tube oscillators of large frequency range. There was also a test set, giving the complex wave used for crosstalk measurements. These oscillators were located near a cathode ray oscillograph on which their wave-forms could be examined by the visitors. A microphone was used also to show the wave forms of the vowels of speech. In all these tests the time

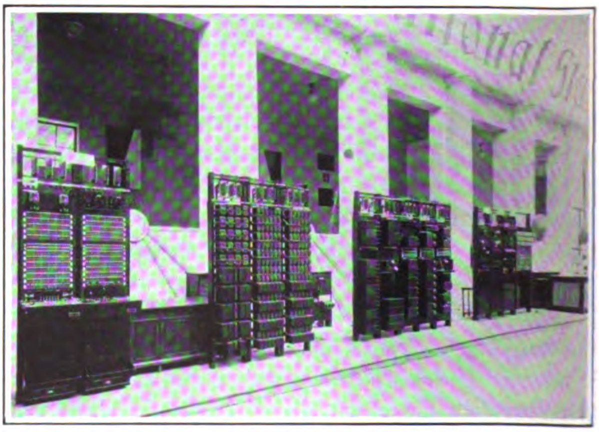

Figure 4—5 KW. Radio Transmitter—Front View.

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[1] "The Prague Radio Broadcasting Station," E. M. Deloraine, Electrical Communication, Vol. 5, No. 3, January 1927.

base was obtained with low frequency oscillating current controlled by a neon lamp.

There could be seen also different types of subscribers' sets, either for local battery or for central battery plants, and for automatic lines. Among them were different models of the French Administration 1924 type, manufactured by Le Matériel Téléphonique, and chosen by the Administration as the standard set.

Next were a few examples of radio apparatus, including a two-tube receiving set, made in Antwerp, an amplifier and the associated Kone Loudspeaker. The exhibit included also a field strength measuring set, developed in London, used for the determination of antenna efficiency. The field to be measured could be adjusted to a value as low as one microvolt/metre. At the back of the broadcasting station, was a 50 watt point-to-point transmitter, of the type used in whalers.[1]

A collection of vacuum tubes showed the types employed in repeater equipment and those for radio telephony. Among them was the 10 KW. water-cooled tube with pyrex glass envelope used for large broadcasting stations, such as the Rugby station on the transatlantic radio-telephone circuit.[2]

The chief items of importance among the telegraph exhibits were two No. 14 Morkrum Teletype Printers,[3] operating upon an artificial line, and a Keyboard Perforator[4] and a Tape Transmitter for the Baudot Multiplex System.

The train or tram dispatching installation consisted of a dispatcher station and three way-stations.

Exhibits of the Telephone and Telegraph Administrations

Instructive features were to be observed in the Exhibition of the Telephone and Telegraph Administrations, located in the Villa del'Olmo itself.

The Austrian Administration exhibited among other items the Hauck type battery made in 1866 at Vienna, a diagram of the first duplex telegraph experiments carried out at the Vienna Imperial Academy of Science in 1853, a complete collection of parts of telephone and telegraph installations, and a map of the Austrian cables.

The French Exhibit comprised some historical apparatus, including Bourseul's receiver and Branly's coherer. There were also parts of a small broadcasting station and of a short wave station and a model of the buildings and antenna of the Bordeaux-Lafayette wireless station. It was completed by some examples of aerial lines, switchboards and subscribers' sets, among which the type 1924 handset made by Le Matériel Téléphonique, and chosen by the Administration as a standard set, could be seen.

The German Administration had gathered a number of early models of telegraph sets, among which those of Steinheil, Gauss and Werner were especially to be noticed. It also had a collection illustrating the history of the electric cell, from a Volta's "pila" to the modern telephone cells.

The General Post Office of Great Britain showed a model of one of the Rugby masts for the transatlantic radio-telephone station and for their long-wave radio-telegraph stations. In front of the mast were a number of early models of vacuum tubes. The historical part contained a d'Arsonval microphone and receivers of the Bell and Reiss type. The modern apparatus included some measuring sets, particularly for checking microphone efficiency.

The Dutch exhibit included photographs, drawings, and parts of equipment, illustrating the short-wave links between Holland and Java.

The Hungarian Administration exhibited two models of the wireless station at Csepel and Szekesfehervar and a great deal of apparatus manufactured by leading Hungarian firms.

The exhibition of the Italian State was very important, as a great number of government departments had taken part in its preparation. A special commission had been appointed by the King of Italy for the publication of a national edition of Volta's works; the volumes ready at the time of the Exhibition were exhibited as well as photographs of Volta's most interesting manuscripts and apparatus (Figure 5).

[1] "Radio Telephony Applied to Antarctic Whale Hunting," E. A. Rattue, ELECTRICAL COMMUNICATION, Vol. 5, No. 4, April 1927.

[2] "Transatlantic Radio Telephony—Radio Station of the British Post Office at Rugby," E. M. Deloraine, ELECTRICAL COMMUNICATION, Vol. V, No. 1, July 1926.

[3] "Morkrum—Kleinschmidt Printing Telegraph Systems," H. P. Clausen, ELECTRICAL COMMUNICATION, Vol. 5, No. 3, January 1927.

[4] "A New Keyboard Perforator for the Baudot Printing Telegraph System," A. E. Thompson, ELECTRICAL COMMUNICATION, Vol. 3, No. 4, April 1925.

A collection of Marconi's first radio telegraph transmitters and receivers and early radio-telephone transmitters was shown; and among other historical apparatus, the Istituto Superiore Postale Telegrafico Italiano sent the transmitter used in the radio-telephony experiments[1] between Rome and Tripoli in 1908.

The Italian Services exhibited telephone and radio-telephone sets specially made for specific purposes. The Italian Navy had erected, near the side of the lake, a short-wave wireless telegraph station, using a simple self-oscillating water-cooled tube of the 10-KW. type.

The Japanese Administration sent photographs showing automatic exchanges in course of installation in Tokio and the development of radio, in which the International Standard Electric Corporation and its Associated Company, the Nippon Electric Company, Ltd., are playing a very large part.

A representative collection of apparatus used in Sweden was completed by a luminous map showing the rapid development of the telephone plant, particularly in the northern part of that country.

The Swiss Administration exhibited some of their earliest switchboards. A map illustrated the efforts made to provide adequate national and international service.

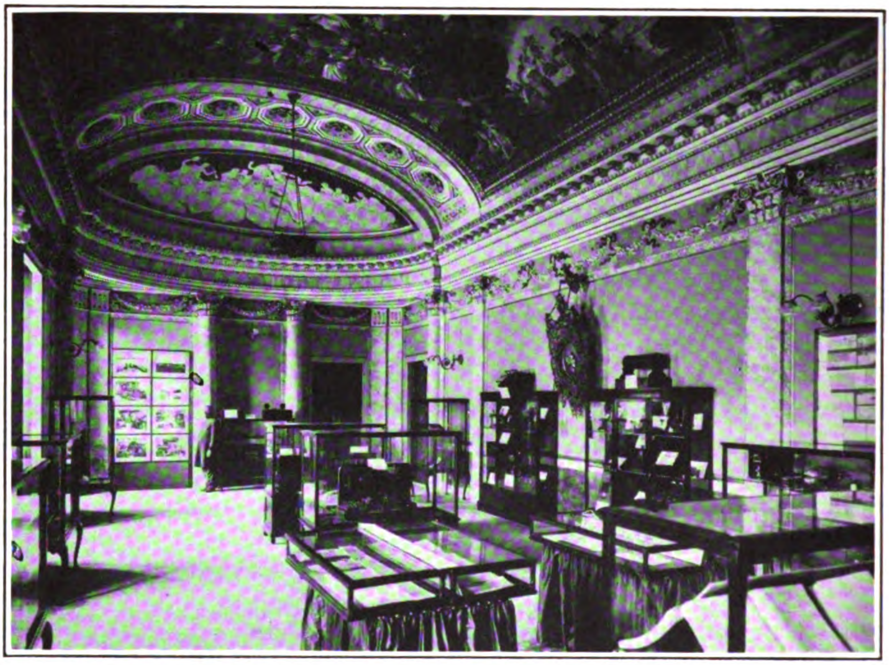

Figure 5—Italian State Exhibit, Including Volta Relics.

A few models of telephone poles and a number of photographs illustrated the work of the Czecho-Slovakian Administration and particularly the beginning of their cable network.

In addition, the American Telephone and Telegraph Company's exhibit presented a general survey of the activities of the Bell System, together with the important steps in the history of telephony in the United States. A replica of Dr. Bell's Exhibit at the Centennial Exposition at Philadelphia in 1876 could be seen. There were three models of the first commercial telephones employed in the United States, and also a working model of the first commercial switchboard. It had eight lines and was installed in 1878 to connect fifty subscribers at New Haven, Connecticut.

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[1] See Jour. Inst. E. E., Vol. 64, November 1926, page 1113.

Meeting of Telephone and Telegraph Engineers at Como

SEPTEMBER, 1927

I. Fourth Reunion of the Comité Consultatif International
II. International Congress of Telephony and Telegraphy

I. Fourth Reunion of the Comité Consultatif International des Communications Téléphoniques à Grande Distance

THE regular meetings of the C.C.I. ordinarily take place at their headquarters in Paris. This year, on a special invitation from the Italian Telegraph Administration, the fourth reunion of the C.C.I. was held at Como from September 5th to 11th, concurrent with the commemoration of the centenary of Alessandro Volta.

The series of meetings, comprising morning and afternoon sessions, were held at the Villa Margherita, a beautiful villa on the shore of Lake Como, which together with its extensive grounds has been purchased by the town of Como for the use of the general public.

The questions under discussion following previous practice were divided into a series of five groups, as follows:

1st Group	General Organisation
2d Group	Protection, Corrosion, etc.
3d Group	Transmission
4th Group	Standard Reference System
5th Group	Traffic and Exploitation.

The outstanding decisions taken in the discussion are briefly described below under the headings of their respective groups.

FIRST GROUP—GENERAL ORGANISATION

A new arrangement was made regarding the election of the President. In future there will be no permanent president, but at the commencement of each reunion a president will be elected who will hold office during the period of that reunion. Under these rules Professor di Pirro was elected President for the Como sessions.

In view of the possibility of the extension of circuits to Constantinople and Asia Minor, it was decided to invite the Telephone Administrations of Albania, Bulgaria, Greece and Turkey to join the C.C.I.

It was further decided that the next meeting should be held in Paris next year during the last week in May and the first week in June.

SECOND GROUP—PROTECTION, CORROSION, ETC.

On the questions of protection, corrosion, chemical action and associated problems, the C.C.I. already has the co-operation of the following bodies:

International Union of Railways
International High Power Conference
International Union of Producers and
  Distributors of Electricity

It was decided to write to the International Union of Tramways with a view to obtaining their co-operation also.

The discussions were largely centred around questions of corrosion and chemical action, and the sub-commissions report which had been drawn up at The Hague last July was adopted with some modifications.

THIRD GROUP—TRANSMISSION

The question of admissible losses on long distance circuits were discussed and the limits already laid down were more definitely stated, particularly in view of their application to switched circuits.

The requirements which international open wire lines should fulfill was discussed. Advice already given was amplified to include some additional electrical requirements and also some mechanical requirements.

Some advice was formulated regarding the use of intermediate cables in open wire lines, particularly where repeater operation was involved, and some practical details of methods were contributed in the form of memoranda by the International Standard Electric Corporation and Messrs. Siemens and Halske.

The above questions were covered in a report drawn up by a sub-commission appointed at the last reunion. The report was adopted with some minor modifications.

The transmission unit was again discussed, it having been decided at the previous reunion that both the unit on the common logarithm basis and the unit on the naperian logarithm basis should continue to be used concurrently. The former, which had been referred to variously as the natural unit, $\beta 1$ unit, etc., is to be known as the nepér with symbol "n," whilst the latter, which has been known as the TU, is to be called the decibel with symbol "N." For the purposes of C.C.I. transactions the full names of nepér and decibel will be used.

Two sub-commissions of special interest were nominated: one, under the direction of Great Britain, to investigate the question of the co-ordination of wireless and land telephony with special reference to the possibility of extending the transatlantic service to Europe generally; the other, under the direction of Switzerland, to deal with international symbols and to obtain the co-operation of the International Electrotechnical Commission.

It was decided that the vocabulary, a draft of which had already been issued, should be revised and all terms rigorously excluded which do not purely apply to telephony and telegraphy.

Fourth Group—The Standard Reference System

The installation of the Standard Reference System is expected to be completed early in 1928, when a representative of the American Telephone and Telegraph Company is expected to arrive in Paris.

A Permanent Commission, under the direction of Captain Cohen of the British Post Office, has been set up to deal with all questions relating to the practical use of the Standard Reference System. This Commission will make all necessary arrangements regarding the installation and maintenance of the Reference System.

At the general plenary assembly the C.C.I. expressed its very cordial thanks and appreciation both to the American Telephone and Telegraph Company for its generosity in providing the Standard Reference System, together with the advice and service of its engineers, and to the French Administration for having arranged an ideal location free of cost to the C.C.I. A vote of thanks was also accorded to Captain Cohen for the work he has done on this important subject.

Fifth Group—Traffic and Exploitation

The simplification of international accounts was discussed and it was decided to try an experimental method over a period of three months. A number of operating detail questions were discussed and arranged. Some discussion was devoted to the multiplying factor to be used in estimating the tariffs over circuits which included submarine cable.

The possibility of leasing international private wires was discussed and a principle was agreed to for international land lines where spares were available.

A traveling commission was appointed to study the question of handling the traffic between the various Bourses throughout Europe. In some cases this traffic amounts to as much as 90 percent of the international traffic.

II. International Congress of Telephony and Telegraphy

A feature of the celebrations inaugurated in Italy this year by the Italian Government to do honour to the memory of Alessandro Volta, the pioneer physicist, who died in Como one hundred years ago, was an International Scientific and Technical Congress dealing with telephony and telegraphy. This congress, to which invitations were issued to leading scientists and electrical engineers throughout the world by a special Volta Centenary Committee, appointed by the Italian Government, was held at Lake Como from the 10th to the 15th of September, 1927. It followed a line similar to that of the congress held in Budapest in September, 1908, which was convened as the result of suggestions made by the Hungarian and French delegates to the International Telegraph Congress held in London in 1904. A second congress of the same kind was held in September, 1910, in Paris, and a third was to have taken place in Berne in September, 1914, but was cancelled on account of the war.

Over one hundred scientists and technicians from all parts of Europe and from the United States of America were present at the Como Congress. Of this number thirty-five came prepared to deliver technical and scientific papers on subjects, bearing on the art of communication by wire and wireless.

Delegates Attending the Fourth Reunion of the Comité Consultatif International at Como, September 5 to 12, 1927. Front Row (seated left to right) are some of the Chiefs of the Administration delegations: M. Muri (Switzerland), M. Hallgren (Sweden), M. Kol (Hungary), M. Heider (Austria), M. Abild (Norway), Dr. Breisig (Germany), Professor di Pirro (Italy)—President of the C.C.I., M. van Embden (Holland), M. Barrillau (France), M. Dethioux (Belgium), M. Chocholin (Czecho-Slovakia), M. Modenov (U.R.S.S.), M. Campé (U.R.S.S.), M. Zuchmantowicz (Poland), M. Constantinesco (Roumania).

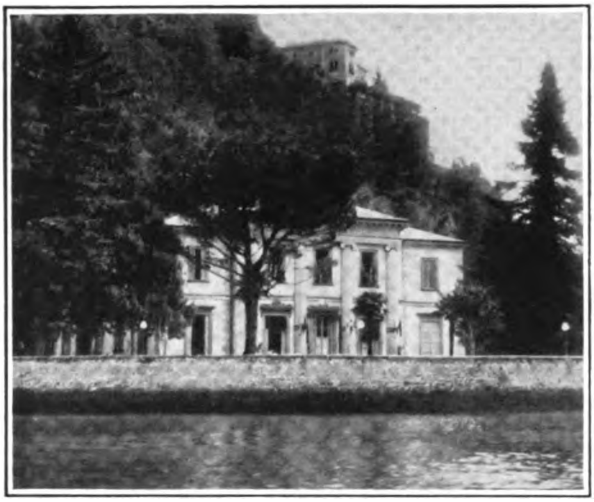
The inaugural ceremony was held on the morning of September 10th in the Great Hall of Villa del'Olmo, the main building of the Volta Centenary Exhibition. His Excellency, the Hon. F. Pennavaria, Under Secretary of State for Posts and Telegraphs, presided and delivered an address of welcome to the delegates. He was followed by several speakers, including the Hon. C. Baragiola, Lord Mayor of Como, Professor Vallauri, President of the Italian Electrotechnical Association, Dr. Alberto Pirelli, President of the International Chamber of Commerce and Dr. G. di Pirro, Director of the Istituto Sperimentale in the Italian State Telegraph Department.

After according to the Members of the Conference a welcome from the Italian industries, Doctor Alberto Pirelli, in his capacity as President of the International Chamber of Commerce, directed attention to the great importance to Members of that Congress—which represented world-wide interests in matters relating to production and exchange—of questions concerning international telephone communications.

He said he had pleasure in seeing present, at the Congress, Members of the International Chamber of Commerce who had participated in the work of dealing with telephone problems. He recalled that at the Conference of the International Chamber of Commerce held in Brussels in 1925, as well as at the recent Conference at Stockholm, the development and improvement of international telephone communication—of such great moment to the commercial world—attracted exceptional attention. He mentioned that, in addition, the Stockholm Conference had established a Permanent Commission for studying such questions, and that they had passed a resolution to ensure constantly increasing collaboration with the International Consulting Committee. He concluded with the assurance that scientific and technical men would find in business men assembled at the International Chamber of Commerce all the moral support they might desire to have for the practical realisation of their projects.

At 2:00 o'clock in the afternoon the delegates to the Congress made a pilgrimage to Camnago, where a memorial wreath was placed on the tomb of Volta, and where delegates were presented to Viscountess Volta, a direct lineal descendant of the great scientist.

At 4:30 P.M. was held in Villa Margherita the first technical session, which was begun with the election of presiding Officers. Professor di Pirro was unanimously chosen President of the



Villa Margherita, where the meetings of the C.C.I. and the International Telephone and Telegraph Congress were held.

Congress; Dr. F. Breisig of the German Reichspost, Dr. G. A. Campbell of the American Telephone and Telegraph Company, Captain B. S. Cohen of the British Post Office and Monsieur H. Milon, Chief Engineer of the French Telegraph Administration, were unanimously elected Vice Presidents.

It was decided that, owing to the large number of papers to be presented (of which a full list is given below) and the shortage of time at the disposal of the Congress, it would only be practicable for those who had contributed memoirs to read brief explanatory summaries and to illustrate them, if possible, by means of lantern slides; and that the language to be used preferably should be French as it was understood best by the majority of the delegates. The first of the abbreviated memoirs was then read.

The following day, being Sunday, no technical sessions were held. A commemoration meeting was held, in the auditorium of the Teatro Sociale, at which delegates of the International Congress of Physicists (which, under the presidency of Sir Ernest Rutherford, also held a series of meetings at the Istituto Carducci in Como) as well as members of the International Electrotechnical Commission, convened at Bellagio, were present. The Lord Mayor of Como, as President of the Volta Centenary Committee, welcomed the delegates on behalf of the city of Como. After brief addresses by Professors Majorana, Vallauri and di Pirro, Senator Antonio Garbasso delivered the memorial oration on the life work of Volta. Homage to the great Italian genius was also paid by scientists from other countries, notably by Dr. A. E. Kennelly of Harvard University, Professor Paul Janet, dean of l'Ecole Superieure d'Eléctricité, Paris, Dr. Max von Laue of Berlin University and Sir Ernest Rutherford, President of the Royal Society of Great Britain, who dealt particularly with Volta's association with the work of the Royal Society.

The inaugural speeches in the Great Hall at Villa del'Olmo, as well as those delivered at the memorial service in the Teatro Sociale, were broadcast from the 5 KW. broadcasting station, installed by the International Standard Electric Corporation at the Volta Centenary Exhibition.

The delegates attending the meeting and accompanying ladies, numbering in all over seven hundred, were entertained at luncheon in Hotel Plinius by the city of Como.

During the first four days of the following week (Sept. 12–15) the technical sessions were resumed with morning and afternoon meetings, during which the various lecturers gave résumés of their papers, the majority of which were illustrated by lantern slides. As will be seen from the appended list, the topics covered a wide range of subjects connected with telephony and telegraphy, including transmission by radio and television. Many of the papers aroused animated discussions, signifying the interest aroused by the subjects presented. It is under-

Four Leading Mathematicians at the International Congress of Telephony and Telegraphy at Como, September 10 to 15, 1927. (Left to Right): Dr. Carson (U. S. A.); Dr. Breisig (Germany); Dr. di Pirro (Italy); Dr. Campbell (U. S. A.).

stood that in due course the papers and discussions will be published, giving a full record of the proceedings.

On the lighter side of the Congress the Italian hosts provided an excellent programme of entertainments for their guests. This included excursions on the beautiful Lake of Como, a performance of Puccini's posthumous opera "Turandot" at the Teatro Sociale, visits to the Centenary Exhibition, where during the first evening of the Congress an official dinner was tendered to the delegates and ladies accompanying them. The Congress closed with a dinner at Hotel Plinius, the President of the Congress, Dr. di Pirro occupying the chair. The Italian State Railways granted reduced fare tickets to the delegates for travel all over Italy, the tickets being valid for one month after the closing of the Congress.

At the conclusion of the proceedings a restricted number of invitations were issued by the Volta Committee to members of the Congress to visit Rome and participate in the final celebrations to be held there in honour of Volta. These celebrations included, on the 19th, a reception in the Capitol, under ideal weather conditions.

Senator Marconi delivered an eloquent address on the pioneer work in physics of his great countryman, Volta. This was attended by the members of the Electrotechnical Commission and of the Congress of Physicists, as well as by the delegates from the Telephone and Telegraph Conference.

On the following day, after laying a wreath on the tomb of the "Unknown Soldier," the delegates visited the Forum, the Colosseum and the Palatine, being conducted by guides speaking different languages, who had an expert knowledge of Roman history and archeology. A luncheon was given at the Palace of the Caesars and in the afternoon, after a short visit to the outskirts of the city, including a drive along the Appian Way, the delegates were received personally by Signor Mussolini at the Villa Torlonia, where tea was served in the beautiful gardens, to the accompaniment of an excellent programme of music. The delegates were honoured also by an invitation to be presented to His Holiness the Pope on the 21st of September.

It is difficult to estimate the exact value of a Congress of this kind. The contributions made on recent technical and scientific progress in telephony and telegraphy will constitute an important source of information to those interested in the subjects dealt with. Of no less importance, however, are the closer friendships, which are formed between communication engineers from all the countries represented, friendships which are based on a better understanding of the other man's problems and an appreciation of the work which is being carried on in the various countries to further scientific and practical progress in telephony and telegraphy.

Papers Presented at the International Telephone and Telegraph Congress at Como—September 10–15, 1927

Breisig, Prof. Dr. F. (Berlin)—Logarithmic measures of ratios between quantities of like nature and their place in the absolute system of measurements

Bubenik, Prof. Dr. Ing. (Brno)—The influence of high tension lines upon telephone lines

Buckley, Dr. O. E. (Bell Telephone Laboratories, New York)—High-speed Ocean Cable Telegraphy

Campbell, Dr. G. A. (American Telephone and Telegraph Co., New York)—The practical application of the Fourier integral

Carson, Dr. J. R. (American Telephone and Telegraph Co., New York)—The present status of wire transmission theory and some of its outstanding problems

Cohen, B. S. (London)—Apparatus standards of telephonic transmission and the technique of testing microphones and receivers

Collet, Ing. L. J. (Paris)—Notes on the general theory of bi-polar and quadri-polar systems

Di Pirro, Prof. Dr. G.—On certain types of electric circuits with constants varying from point to point

Erikson, P. E. (International Standard Electric Corporation, London)—The present state of long-distance cable telephony in Europe

Giebe, Prof. Dr. E. (Berlin)—Piezo-electric crystals as frequency standards

Giorgi, Prof. Ing. G. (Rome)—Wave filters and infinite lines, subjected to variable currents of an arbitrary form

Hansford, Dr. R. Y. (London)—A modern long-wave, high-power radio telephone and telegraph station, using thermionic valves

Hartley, R. V. L. (Bell Telephone Laboratories, New York)—Frequency relations in electrical communication

Hirsch, Ing. R. (Telefunken, Berlin)—Progress in the technique of long-wave high-power stations using high-frequency alternators

Hoepfner, Ministerial Councillor (Berlin)—The technical exploitation of long cables

Kennelly, Prof. Dr. A. E. (Harvard University, U. S. A.)—The application of hyperbolic functions in the recent progress of submarine telegraphy

Korn, Prof. A. (Charlottenburg, Berlin)—Photo-telegraphy and the problem of television

Küpfmüller (Berlin)—On certain relations between the frequency characteristics and the transient phenomena in linear systems

Leithauser, Prof. Dr. (Berlin)—A new method for the exact measurement of wave lengths from distant transmitting stations

Le Corbeller, Ing. Ph. (Paris)—The Loudspeaker

Lo Sudro, Prof. Dr. A. (Rome)—The saturation current of thermionic valves

Majorana, Prof. Dr. Ing. Q. (Bologna)—A new system of telegraphy by visible light and by ultra-violet rays

Meissner, Dr. Ing. (Berlin)—On radiation in space with horizontal polarization

Pages, Ing. A. (Paris)—Multiplex telegraphy at audible frequencies

Pleijel, Prof. Dr. H. (Stockholm)—On the theory of homogeneous parallel lines

Pohlmann, B. (Berlin)—On loaded submarine cables

Pollaczek, Dr. (Berlin)—The influence of the earth on the electromagnetic field of waves transmitted along aerial lines and on the mutual induction between parallel lines

Pupin, Prof. Dr. M. I. (Columbia University, U. S. A.)—A new type of artificial line for duplex working of submarine cables

Robinson, C. (London)—The submarine link in international telephony

Rukop, Prof. Dr. H. (Berlin)—On the progress made in short-wave radio telegraphy

Salinger, Dr. H. (Berlin)—On the conditions governing the speed of telegraph transmission

Schroeter, Dr. Phil. F. (Berlin)—Recent progress in tele-photography with the Telefunken-Karolus-Siemens system

Turpain, Prof. Dr. A. (University of Poitiers) —The use of very short waves in radio telephony, employing conductors

Vallauri, Prof. Ing. G. C. (Turin)—Absolute measurement of radio-telegraphic frequencies, produced by piezo-oscillators

Wagner, Prof. Dr. W. (Berlin)—Electric wave filters

Providing Madrid with Automatic Telephone Service

By KENNETH McKIM

Information Department, International Telephone and Telegraph Corporation

ON December 29, 1926, the Spanish capitol joined the large and constantly growing group of cities that enjoy automatic telephone service, for on that day a multiple office machine switching system serving the entire city was cut over simultaneously. The importance of this event to the people of Madrid was recognised by His Majesty King Alfonso XIII, who presided at the inaugural formalities, and who set in motion the shafting of the No. 7-A Rotary Standard Electric switching equipment.

It was the culmination of an intensified effort to provide for a city of approximately a million inhabitants, an entirely new telephone plant in sixteen months, a task that involved not only the substitution of automatic for manual service, but also the erection of buildings, the planning of a distributing system that would serve as the foundation for all future plant expansion, and the construction of an underground cable network, amidst the difficulties characteristic of Old World cities.

Enough time has now passed since the event to give assurance to the statement that the Rotary equipment is affording the utmost satisfaction both to the Compañía Telefónica Nacional de España and to the public, and that the people of Madrid have found that automatic telephony far exceeds their greatest expectations. The contentment is so general and has become so widely known that eighteen other Spanish cities in which the company is preparing to inaugurate Rotary automatic service within the next two years are exhibiting keen anxiety for this reform.

Owing to the condition of the old manual plant, parts of which had been in service twenty-five years, it was found impracticable to consider the conversion of the exchanges to automatic separately. It was decided, therefore, to install a complete new and independent local plant to be put into service at one time. Although this procedure was difficult, and contrary to general practice in the conversion of local service from manual to automatic in large cities, inspection of the old manual plant of Madrid showed the necessity for this procedure.

The overhead outside distributing plant consisted of wires that stretched over the house tops from wooden structures that stood like violin bridges on the cornices and ridge poles of buildings. From tall steel towers at street corners and in the plazas, cables hung in long festoons or were "draped" between the house top structures. The circumstance that the towers were necessarily higher than the houses, added neither to the esthetic appearance of the city nor to the facility for maintenance.

When the Compañía Telefónica Nacional de España acquired the various state and private telephone plants of Spain in 1924, with a concession to develop and operate an efficient nation-wide system, Madrid had a toll office and three manual exchanges, the latter named Mayor, Jordan and Salamanca, with capacities, respectively, of 5,600, 3,480 and 3,600 lines. Of these, Mayor (Figure 1) situated on the historic Puerta del Sol, served the central portion of the city, and was correspondingly congested. The switchboard was of a lamp signal local battery multiple type, and was installed in 1910.

The Jordan and Salamanca common battery exchanges were opened in residential sections of the city in 1916 and 1917, respectively. To tide over the emergency until the new automatic plant could be made ready, the company in January, 1926, opened the Hortaleza exchange in the business part of the town. This exchange was equipped with a modern common battery multiple switchboard, type No. 2001-D, with sixteen trunk and subscriber positions, and equipped for 1,200 lines. It was put into service to provide some relief to the overloaded Mayor switchboard.

Here also was installed an 18-position No. 2001 toll switchboard, to which ten more positions were added in December, 1926, and a No. 4 toll testboard. The long distance exchange took the place of the antiquated boards which had handled the city's toll business previously and which were located in a building situated at the entrance to the Puerta del Sol.

As subscribers formerly had been permitted to buy their own telephones, there were in service in Madrid instruments of various ages and makes, especially of the magneto types connected with the Mayor exchange (see Figures 2, 3 and 4). Many were far more attractive to the eye than helpful to the ear. Private branch exchanges, also the property of subscribers, were similarly diverse. In planning new inside and outside plant to take the place of this curious assemblage, careful and thorough study of the requirements of the city was a preliminary necessity. This was started immediately after the concession was granted, and was based on the estimated telephone developments for the next twenty years. On August 27, 1925, after consideration of all factors concerned, it was decided to adopt No. 7-A Rotary automatic equipment [1] and work was started at once on three exchanges for the initial installation, two of 5,000 lines each, and one of 7,000. Floor capacity for expansion to meet the full requirements of their respective areas was provided in the first two cases. Property was acquired adjoining the Salamanca manual exchange, and a permanent building was erected there with room for 20,000 lines of switching equipment. On February 6, 1926, this building was ready. This permitted the installation of the first 5,000 line unit to commence. The Jordan manual exchange building was remodeled, and on January 16, 1926, a crew began the installation of the first 5,000 lines. This exchange also has an ultimate capacity of 20,000 lines.

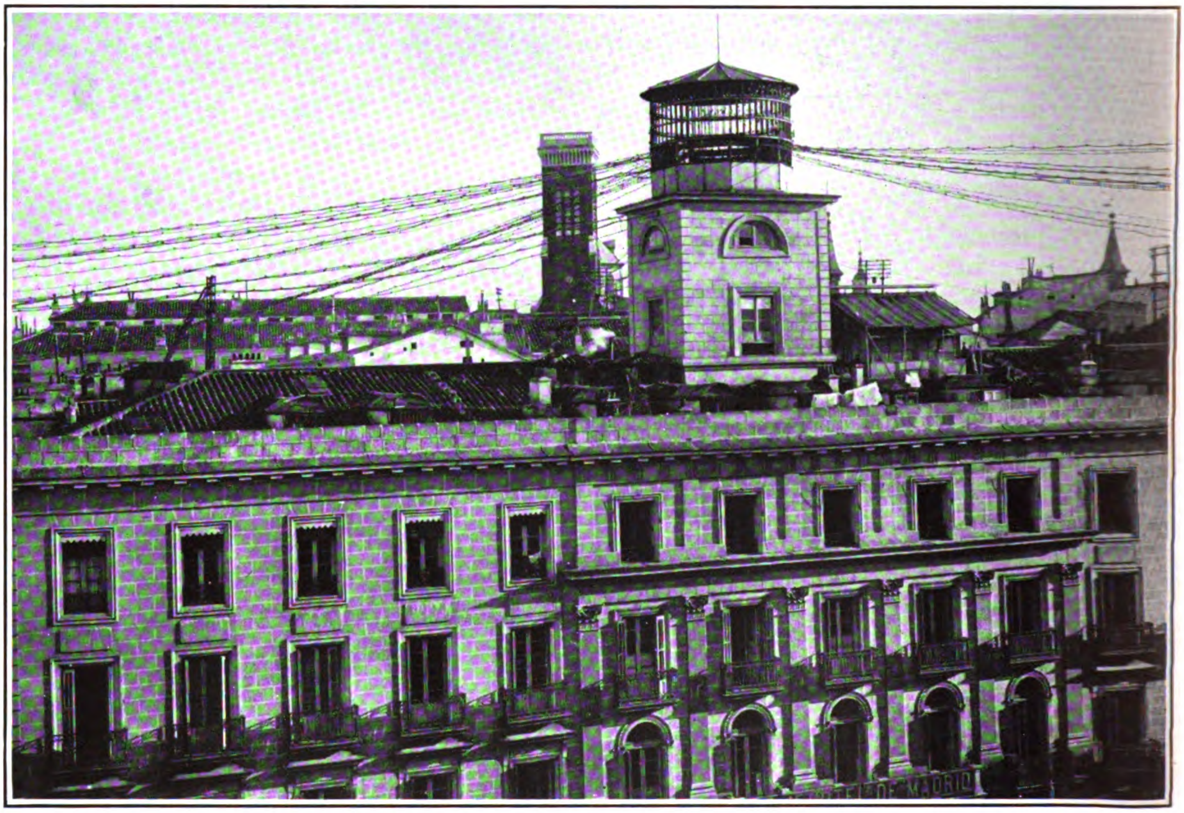


Figure 1—Overhead Wires and Cables Entering the Mayor Manual Exchange, Madrid, through a Tower on the Roof. The housetop construction, typical of the old outside distributing plant, may be seen on the horizon.

In the case of the exchange to supplant the Mayor and Hortaleza manual exchanges a special problem was presented. The Company had bought a large and magnificently situated vacant plot on Gran Via, at the centre of the city, with the intention of erecting a fourteen-story headquarters building which at the time would accommodate an automatic exchange with an ultimate capacity of 40,000 lines. But to wait for the completion of such a structure would have greatly retarded the reformation of the local telephone service, with which the public was justifiably dissatisfied.

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[1] "No. 7-A Machine Switching System," G. Deakin, Electrical Communication, Vol. 3, No. 3, January 1925.

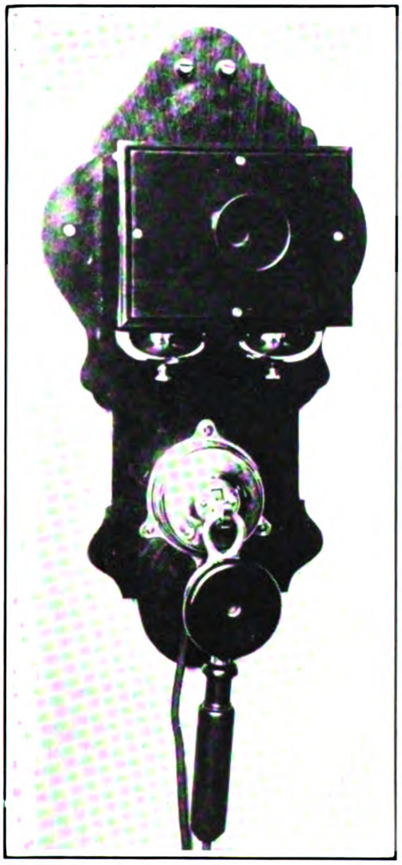

Figure 2—Old Telephone, Peninsular B.C. Type A, One of Those Used in Spain before the Compañía Telefónica Nacional de España Began to Operate the Spanish Telephone System.

In the interests of the subscribers, therefore, it was decided to put up at the rear of the plot a provisional building large enough to house 10,000 lines. This building could be abandoned when the permanent headquarters building was finished and it could be equipped with an automatic installation to be cut over without prejudice to public needs. The construction of this emergency building was started on November 13, 1925, and on March 8, 1926, the installation of 7,000 lines of Rotary equipment was begun.

In 1925, the engineers planned the underground cable plant that should supersede the overhead system already described, and that should be ready for service at least by the time the automatic exchanges could be cut over. The first section of trench was opened in October, 1925, in order to take advantage of certain street repairs, although little was actually done toward the construction of the underground system until December 17th of that year. The last trench was closed on May 28, 1926. During that brief time, 280,000 metres of duct were laid under the streets of Madrid. As there was a complete lack of plans of existing underground construction in Madrid, the workmen frequently were running into buried pipes, sewers, electric power cables, etc., at various levels, so that it was necessary in many instances to dig to an extraordinary depth in order to lay the conduit free of interference with these other various underground systems. The narrowness and crookedness of many of the streets in old Madrid added fresh difficulties (Figures 5 and 6).

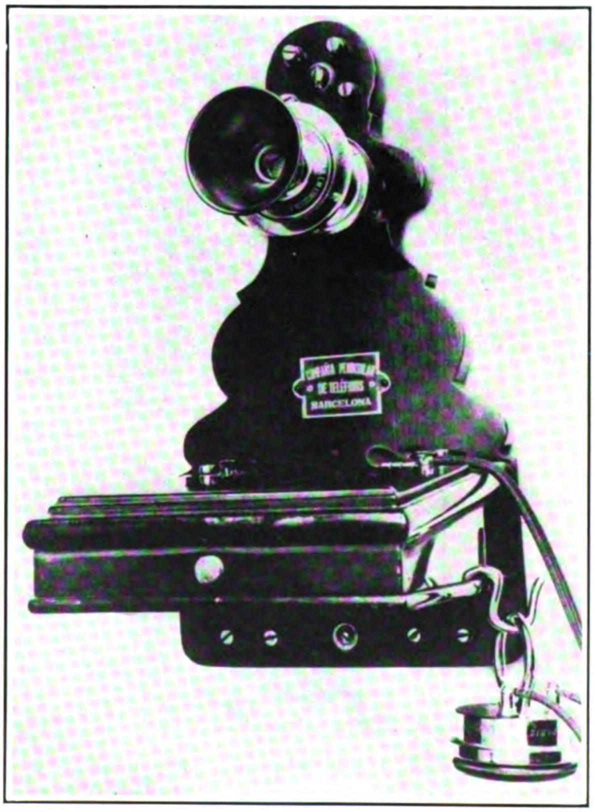

Figure 3—One Instance of the Telephonic Variety Employed in Spain by the Companies Preceding the Compañía Telefónica Nacional de España.

The outside distributing plant was developed with 600 and 1,200 pair cables. Owing to the density of the population, 85.5 per cent of the cables employed were of the 0.51 millimetre conductor class.

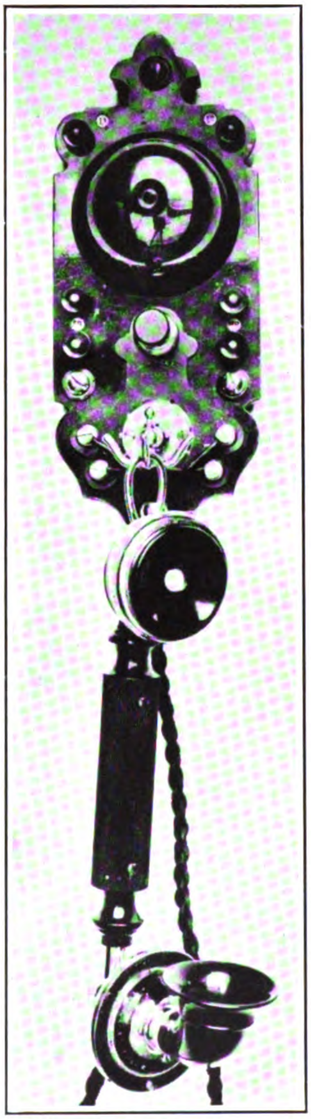

Figure 4—Type in Use in Madrid, among Other Models, before the Advent of the Automatic.

As cable splicing was virtually an unknown art in Spain, and as the Company had adopted a policy not only of using national products so far as possible, but also of employing Spanish personnel, one of the first steps in the development of an underground cable system was the creation of the necessary cable splicers. One school was established in Madrid and another in Barcelona. That the instruction was thorough and the students apt is demonstrated by the fact that the one hundred and twenty cable splicers who were employed in construction of the Madrid outside plant were all Spanish mechanics who had passed through the Company's school, where they had learned the trade from first rudiments.

Owing to the congested and tortuous character of the older parts of Madrid, and to the great number of houses either without basements or common patios, it was found necessary in those sections to install the fachada (or wall) type of distributing cables. To be less visible, these were placed under cornices or balconies wherever possible, and every practicable precaution was taken not to mar the architectural lines or esthetic effect of the fronts of the buildings. To make such installations, an intensive campaign had to be conducted to obtain permits from property owners, but generally when the proposal had been explained to them, a co-operative attitude was met with from the landlords.

In some of the newer outlying areas, the standard American type of aerial cable construction was adopted. A contract was entered into with the municipality to allow the underground cables to be placed in the water-pipe subway, known as the Canal of Isabel II, in portions of the city where that subway passes under the streets. This reduced materially the amount of trenching and served to relieve the public of the annoyance of having some of the principal thoroughfares, such as the new Gran Via and the traffic congested Alcala Street, opened up by construction gangs.

In preparing Madrid for the cut-over to automatic, the Company in a period of about eight months pulled 111,780 metres of cables through the ducts of the underground construction, placed 165,720 metres of the wall type, and erected 91,200 metres of aerial type cables. In the trenching and placing of the ducts, approximately 800 men were employed, and in the construction of the cable plant, 1,255 men.

Figures 7 to 11, inclusive, show views of the Madrid automatic plant. A distinctive feature is that all line finders, sequence switches and

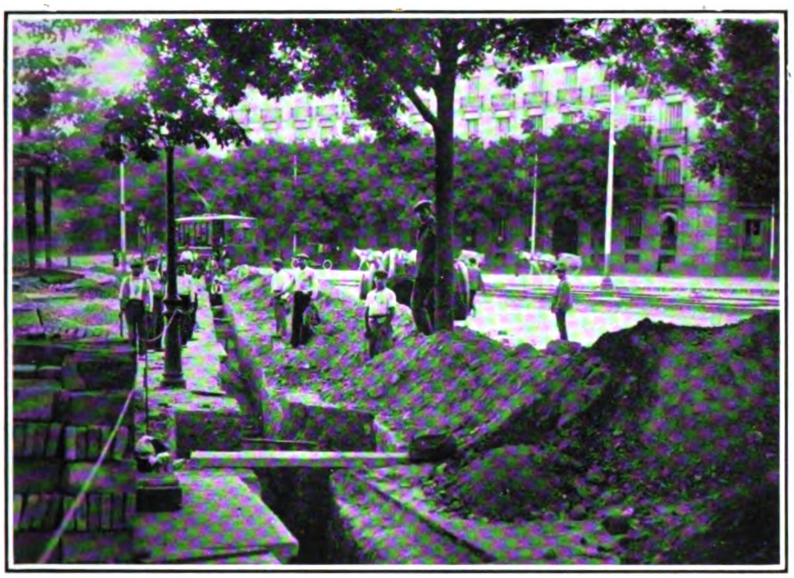

Figure 5—Running a Trench of the Underground Telephone Cable System across the Plaza Colon, Madrid. The variety of pipes and bare cables of other subterranean systems crossing at various levels may be noted.

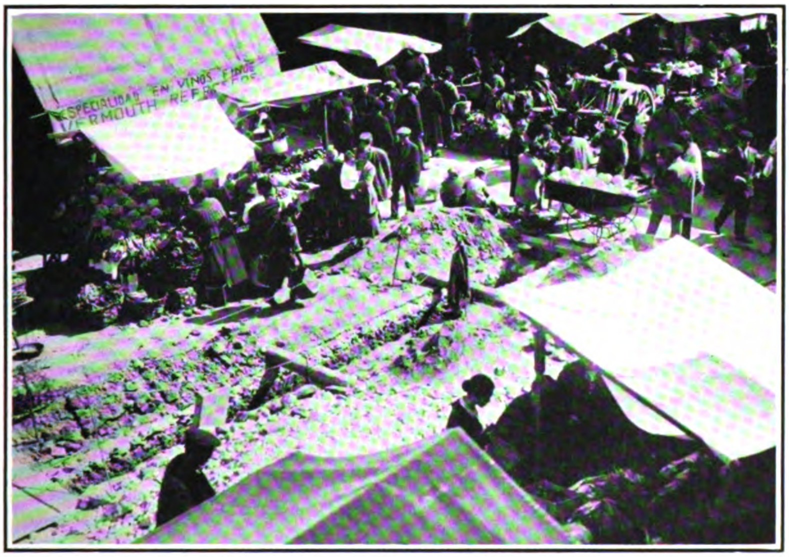

Figure 6—Running the Telephone Cable Trench through a Crowded Market-place in Augusto Figueroa Street, Madrid.

selectors are gear-driven, this being the first multi-office area in which that type of drive has been used exclusively. "The Spanish circuits," as those of the Madrid plant are called, contain many new features, such as the "hold-over" circuit for registers and the automatic release of a register, if held for more than 30 seconds without dialing. Routine testing equipment for line finders, selectors, and registers is provided, together with complete facilities for monitoring and testing inter-office junctions.

The subscribers' lines are cabled from the M.D.F. to terminal strips mounted above the final selector bays, and from there to the final selector arcs, 200 lines comprising one final selector group.

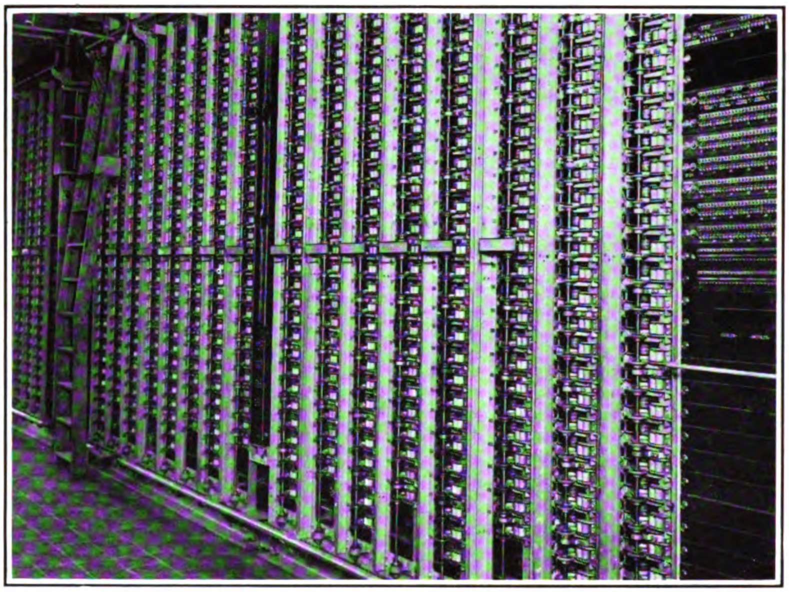

Figure 8—Second Line Finders, Salamanca Exchange, Madrid.

Each line finder bay is equipped for 100 subscribers' lines, the first fourteen line finders which serve this group of 100 lines being mounted in the lower half of the bay, and their associated relays, as well as 100 line and cut-off relays, in the upper half. The A, B and C wires from the line finder arcs and cut-off relays are wired to terminal strips mounted above the line finder bays.

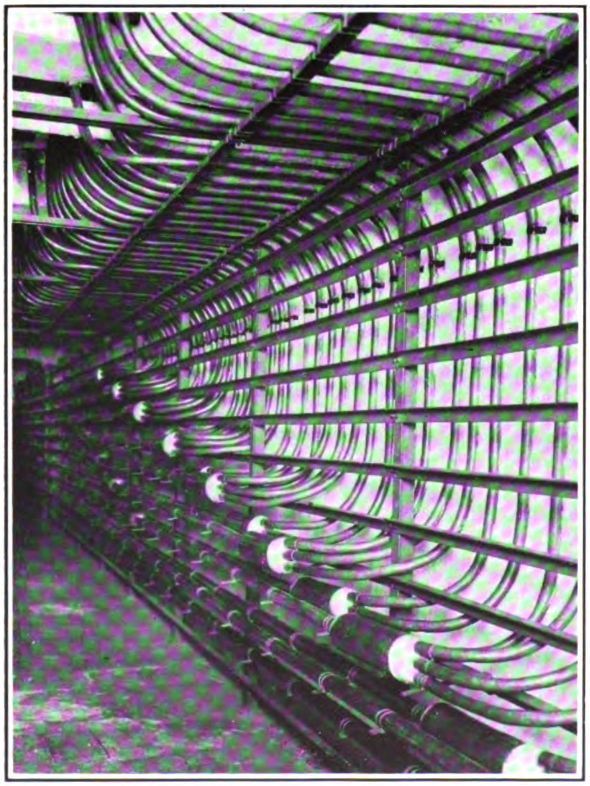

Figure 7—Cable Vault in Jordan Automatic Exchange, Madrid.

The subscribers' lines are connected to the line relays and line finder arcs by means of jumpers from the final terminal strips to the line finder terminal strips, these being, in effect, an I.D.F. for distributing the subscribers' lines to the line finder groups as traffic conditions require.

The number of trunks between offices are as follows:

Gran Via to Jordan	185
Gran Via to Salamanca	124
Jordan to Gran Via	220
Jordan to Salamanca	88
Salamanca to Gran Via	220
Salamanca to Jordan	132

In addition 22 trunks from Jordan and Salamanca to Gran Via for special service two-digit calls and 38 four-digit direct automatic trunks from toll to Jordan, and 27 from toll to Salamanca are equipped.

The number of local second group selectors at Gran Via is 293; at Jordan, 122; and at Salamanca, 78. Gran Via is also equipped with 35 second selectors for special service calls, and 87 four-digit automatic trunks from toll.

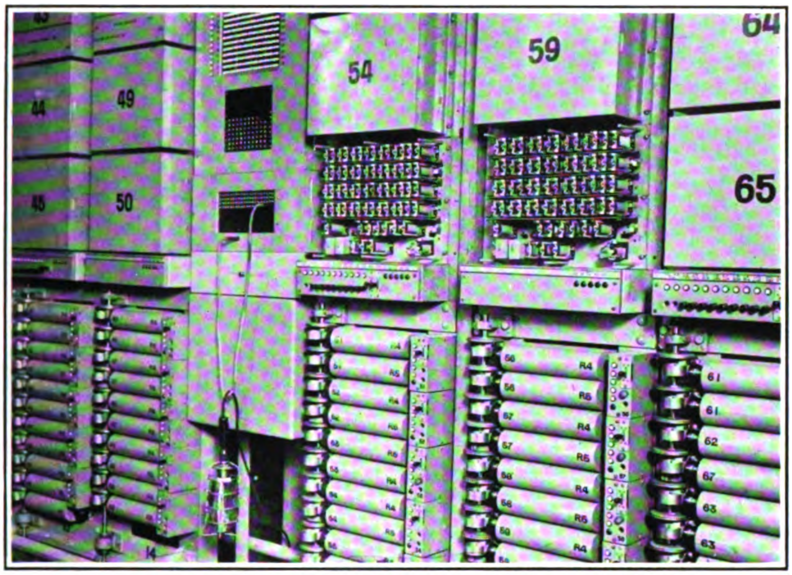

Figure 9—Register Bays, Showing Relays, in the Temporary Gran Via Exchange, Madrid.

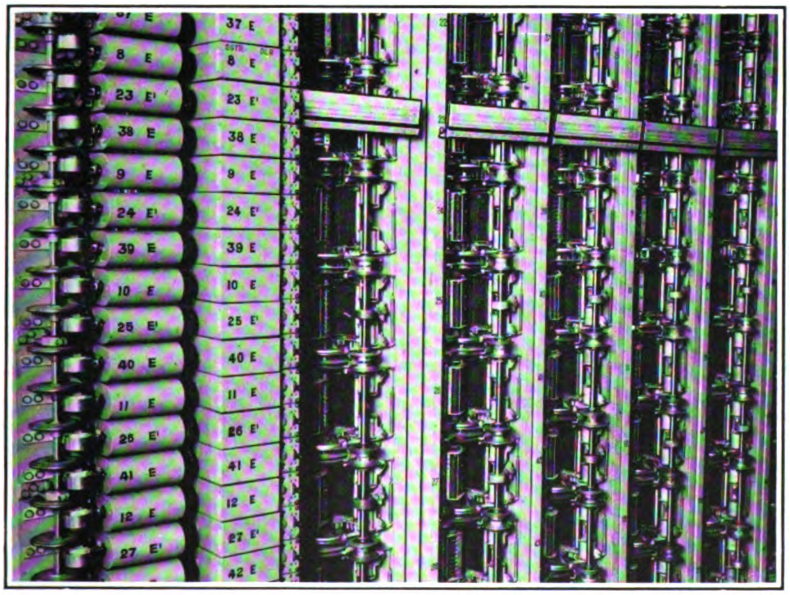

Figure 10—Group Selectors, Salamanca Exchange, Madrid.

The number of register circuits for the 7,000 lines at Gran Via is 95, and for Jordan and Salamanca with 5,000 lines, 68 each.

At Gran Via exchange, ten groups of connecting circuits of 56 circuits each are equipped, and at Jordan and Salamanca, seven groups of 58 circuits each.

The register choosers, associated with each connecting circuit, are 50 point, gear driven line finders with seven brushes, having access to 48 register circuits, two sets of terminals being reserved for other purposes.

The last four connecting circuits in each group at Gran Via exchange are used as automatic 5-digit trunks from the Hortaleza exchange, 200 metres distant, where are installed the toll and toll recording, information, suburban and official P.B.X. boards, the latter being used as a private branch exchange board for the various departments of the Company.

In each of the three exchanges there is provided special first line finder equipment, designed for two-party line selective ringing service. As party line service is practically unknown in Spain, this relatively small quantity of equipment has been provided by the Company in order to promote telephone development and the telephone habit through the introduction of this type of service at a price below the normal rates.

For the ordinary final selector groups of 200 lines, Gran Via has thirty-one groups with 24 finals each; Jordan, twenty-two groups with 20 finals each; and Salamanca, twenty-three groups with 15 finals each.

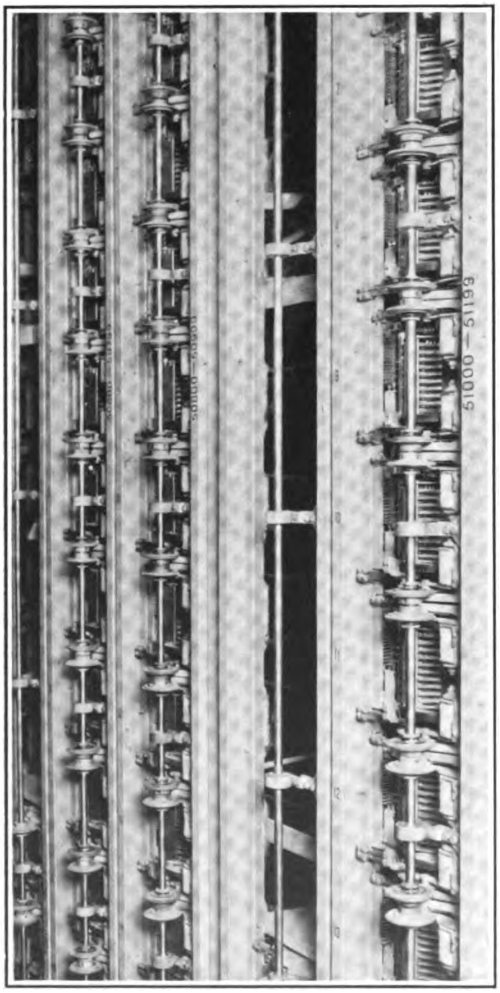

Figure 11—Final Selectors in the Salamanca Exchange, Madrid.

In each exchange, certain groups of 200 subscribers' lines are reserved for private branch exchange service, and are equipped with special final selectors designed for P.B.X. hunting. As the calling rate into these groups is naturally higher than into the ordinary groups, a greater number of final selectors is provided. Gran Via has four groups of 33 finals each; Jordan, three groups of 28 each; and Salamanca, two groups of 20 each. Each group of 200 subscribers' lines is also equipped with one test final and one toll offering final selector.

All relays and sequence switches associated with the various types of selectors are mounted on combined relay and sequence switch bays, with a capacity of 45 circuits each. Adjacent to each sequence switch are mounted the routine test key and a listening and "busy" jack.

Each level on a first group selector has access to 20,000 subscribers' lines, the register circuit being so wired that the 10,000's digits 1 and 2, 3 and 4, etc., are directed to the odd levels 9, 7, 5 and 3, level one being reserved for special service calls, so that the present capacity of the Madrid area is 80,000 lines.

The capacity may be brought up to 180,000 by the introduction of 6-digit dialing, at which time the even levels may be brought into use, the register circuit being so wired that by slight alterations and additions this may be easily accomplished.

The register consists of 4 sets of counting relays and two sequence switches, and is so designed that the 10,000's counting relays can be used to receive the unit impulses from the subscriber's dial. The arrangement of the wiring is such that the registers may be readily converted for use when 6-digit dialing is introduced.

A monitoring and test desk (Figure 12) is provided for each exchange where, by means of jacks and keys any outgoing junction may be tested, or "made busy," or a group of first line finders or subscribers' lines may be placed under observation. The permanent glow lamps (P.G.L.) and jacks are mounted in this desk. These lamps are associated with the connecting circuit and flash when a connecting circuit is disconnected from a register circuit if a subscriber fails to dial within 30 seconds after receiving the dialing tone or between digits or if held by a faulty line. This cuts down the holding time of the registers, and with the larger grouping of registers in the register choosers requires fewer of them.

Mounted in this desk also are the overflow lamps from the first line finders and connection circuits, which indicate when all circuits in any group are busy.

Group switch guard lamps are provided which indicate that the calling subscriber has failed to release after the called party has restored his receiver, and are also used to indicate the number of a connection circuit connected to a register. Associated with each register circuit is a key (F.L.K.) mounted in the panel, below the G.L. lamps, which, if depressed when a register is held by a connecting circuit, will cause the G.L. lamp to burn, thus indicating the number of the connecting circuit connected to that register.

Each register is equipped with a "Hold-over" feature which will hold the register and selector circuits, if for any reason all the impulses are not stepped out of the register after the subscriber has dialed the full number of digits. When the subscriber restores his receiver, his line is freed to make another call, but a lamp (H.O.L.) on the register will light and the faulty call can then be traced out by an attendant.

A complete system of audible and visual alarms is provided throughout the equipment for the purpose of notifying an attendant of all abnormal conditions such as failures of battery or ringing power equipment, and various kinds of subscribers' line troubles.

The power equipment (Figure 13) at each automatic exchange is identical. It includes a 48 volt 4500 ampere-hour battery consisting of 25 cells each, with a tap from each of the last seven cells extending to an end cell switch which is automatically operated to maintain a 48V exchange potential within the limits of plus or minus 2 volts.

The charging equipment consists of two motor driven compound generators with a capacity of 385 amperes at 48–60 V, so arranged that they can charge the batteries or float the load singly or in parallel. When charging, the machines are shunt connected, and when floating the load their voltage is automatically regulated by means of the compound winding in the generators.

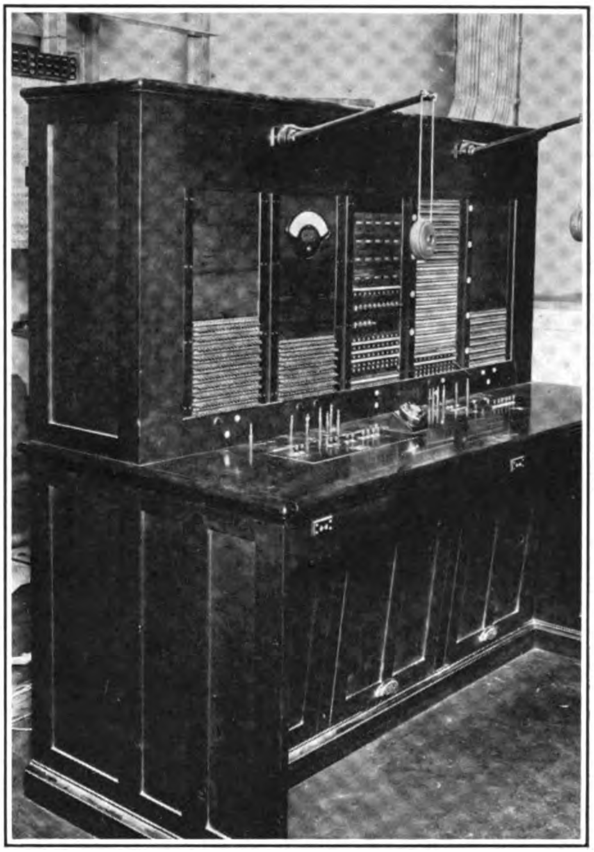

Figure 12—Monitoring and Test Desk.

A reserve engine driven generator-set consisting of a 6 cylinder engine directly connected to a generator is provided for prolonged failures of the commercial power (Figure 14). These sets are capable of supplying current at 220 volts to the motor generator sets for floating the busy hour load, including the switchrack motors, and 110 volts for a reasonable percentage of the switchrack and building lighting.

The switchrack motors are normally operated from commercial power supply of 220 volts; but in the event of failure of the commercial power, a 48 V motor driven from the main battery connected to a 220 V generator is automatically started and current is fed to the switchrack motors in place of the commercial power. This generator also furnishes a limited number of emergency lights for the switchrack.

Owing to varying local conditions, a uniform plan could not be carried out for the cut-over

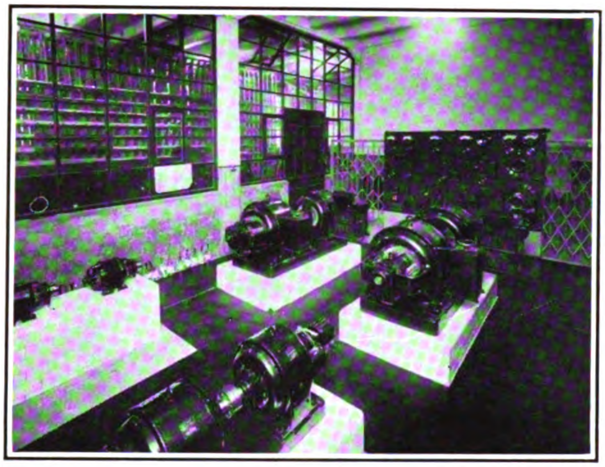

Figure 13—Power Plant with Main Distributing Frame of the Gran Via Temporary Exchange (Madrid) in the Background.

of all of the exchanges. In the case of the old Mayor local battery exchange subscribers who were to be served by the provisional Gran Via automatic office, the plant was completely duplicated. Automatic telephones were installed in the houses of the subscribers, beside the manual magneto instruments, and connected by the underground cable system with the main frame of the automatic exchange, while the manual telephones continued to give service by means of the old overhead connections with Mayor.

In the Jordan and Salamanca offices, the new main frames were installed as closely as possible to the existing main frames of the common battery manual exchanges. As quickly as the underground cables were installed in these two areas, automatic telephones were substituted for manual in the homes of the subscribers. These were connected by means of the underground cable plant to the new main frames, and by jumper wires to the old main frames, thus enabling them to work temporarily as manual common battery telephones. The old overhead wires and cables in the Jordan and Salamanca areas thereupon ceased to appear further in the local service.

It was thus possible in the two exchanges mentioned above to accomplish the cut from the old switchboards to the new Rotary switching equipment by the usual plan of cutting the temporary jumpers and removing the cut-off relay plugs in the new switchboard.

As mentioned in the introduction, the physical cut-over, which was set for midnight to take advantage of the light traffic load, was preceded on the afternoon of the 29th of December with a formal ceremony in which the King, his cabinet, foreign diplomats and upwards of 200 invited guests, representative of the financial, industrial and political life of the nation, took part. This was held at the Salamanca exchange, since it was the only place where there was space available for such a gathering.

A large vacant room on the ground floor of the new building was decorated and provided with long, narrow tables and chairs for the guests and a raised platform at the rear of the room, where a table and seats were placed for His Majesty, General Primo de Rivera, the Infante Don Fernando, General Martinez Anido, Minister of Gobernacion, the Papal Nuncio, the Marqués de Urquijo, President of the Compañía Telefónica Nacional de España, and Colonel José Tafur, Director General of Communications. A reproduction of a photographic view of His Majesty and those who accompanied him is shown in Figure 15. At each seat in the room was a watchcase receiver and a small map of the principal telephone lines in Spain.

The inaugural ceremony started at 3:30 P.M. with an address to the King by the Marqués de Urquijo, in which he outlined briefly the work accomplished by the Company in the two years of its existence.

After dealing with the decision to install automatic plant in the twenty towns of Spain and reciting some statistics in the development

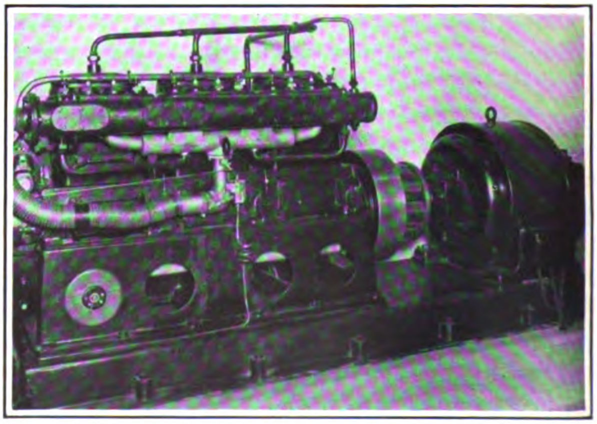

Figure 14—Emergency Gas Engine of the Auxiliary Power Plant, Madrid.

of the new system, both local and long distance, the Marqués announced that as a demonstration of the practical effectiveness of the service, the chief engineer, Mr. F. T. Caldwell, would establish a circuit and enable all present to hear a conversation over a distance of 3,800 kilometres, "a distance never attained in Europe, and one which, if it were established in a straight line, would cross Europe from east to west."

His Majesty the King of Spain.

General Primo de Rivera rose and responded briefly to the Marqués de Urquijo in the name of the Government. The chief engineer then conducted a roll-call of sixteen repeater stations, establishing a circuit that touched San Sebastian on the Bay of Biscay, Barcelona on the east coast of the Peninsula, Ceuta in the Spanish protectorate of Morocco, and, turning north through Madrid, terminated at Coruña, in the northwest corner of Spain.

As the repeater stations responded to the roll-call, lamps lighted automatically on two huge wall maps, enabling the audience with greater ease to follow the course of the demonstration. A small copy of these maps, placed on the table in front of King Alfonso, and provided with tiny green lights, served to visualize the event for the King and those around him.

When Coruña had answered, the King signified his desire to speak over the circuit that had established a new European long distance record, and taking the gold-inlaid telephone that had been provided for him, said:

> "I must congratulate myself as well as congratulate Spain and the Compañía Telefónica Nacional de España upon the magnificent achievement in communication which has just been realized. Nothing gives me greater pleasure than to witness every day the advance of Spain on the road of progress. The most important progress of all is the moral, the ethical. No society can live without refined idealism, nor without the cultural side which familiarizes us with science, and allows us to use its unlimited resources for the good of humanity. From both will spring the principles which will inspire the life of the people. The Spaniard is obliged, more than any other, to fall back on his proud traditions, which have given vitality to nations that are the pride of the world. Without boasting or false illusions, with perseverance and optimism, let us all work for the Spain of today with the mind fixed on the Spain of tomorrow—on the Spain of our sons."

King Alfonso then went on a tour of inspection of the exchange, terminating on the second floor, in the Rotary switching equipment room. Here the Bishop of Madrid-Alcala was waiting in full robes to pronounce his benediction upon the plant which was to provide the future telephone service for the capital of Spain. Following this solemn act, His Majesty threw a switch arranged to set in motion the shafting in the exchange. Thus ended the impressive ceremonial part of the cut-over.

At 11:55 P.M. operators on the manual switchboards began to challenge calls.

The various steps of the cut-over may be followed in the accompanying work schedule (Table I) which was carried out that night on a strict time basis, with a dispatcher who handled all movements by telephone. In general, the trunks to the toll board were first released and cut into the automatic plant, after which the subscribers' lines were cut over from the manual to the automatic service.

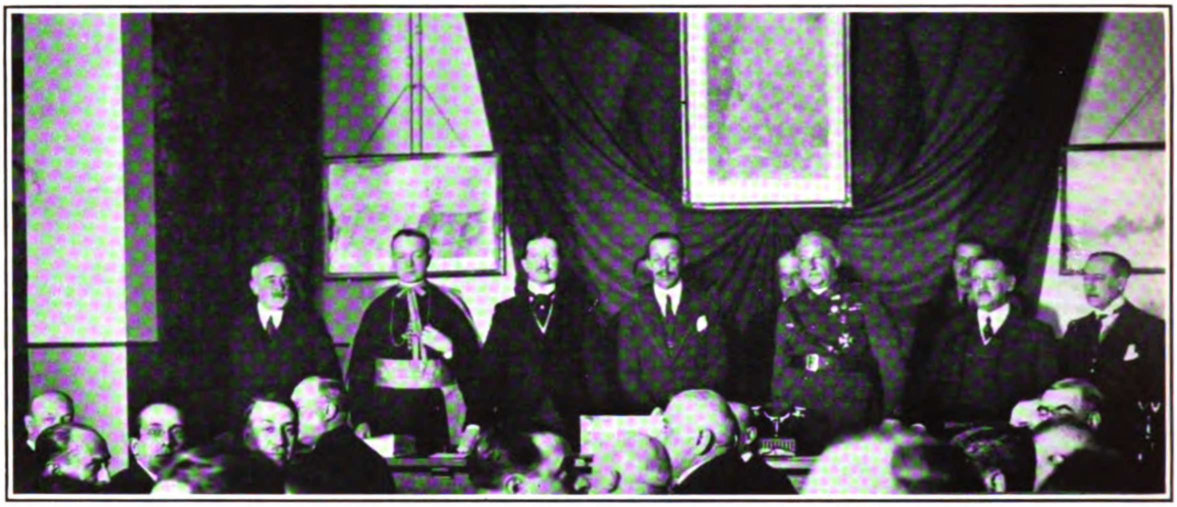

Figure 15—King Alfonso XIII and Those Who Accompanied Him at the Demonstration of Long Distance Service in Madrid on the Occasion of the Inauguration of the Automatic Plant, December 29, 1927. From left to right—Colonel José Tafur, Director General of Communications; the Papal Nuncio, Mgr. Tedeschini; Infante Don Fernando; H. M. King Alfonso; General Primo de Rivera; General Martinez Anido, Minister of the Interior; the Marqués de Urquijo, President of the Compañía Telefónica Nacional de España and Vice President of the Standard Electrica, S. A.

In the case of the Salamanca and Jordan exchanges, the cables from the manual switchboards to the manual main frames were first cut at the terminal blocks, as representing the quickest method of severing the connections and the cut-off relay plugs were pulled, thus establishing automatic service, after which the jumper wires between the new and old main frames were cut and removed.

Subscribers of the old Mayor exchange were given automatic service by pulling the plugs on the cut-off relays. A little while later, the operators of Mayor exchange were sent home, and the battery switch was withdrawn.

Notwithstanding the hour selected for the cut-over, Madrid started with a highly abnormal traffic load. Curiosity was the predominating cause. During the first few days the traffic went as high as 300 percent above normal and then gradually settled down to a new calling rate about 50 percent higher than had existed on the old system.

The curiosity load is easy to explain. In the first place, local service in Madrid had been far from ideal, even after the Compañía Telefónica Nacional de España took over its operation in 1924 and effected such reforms as were practically possible. Although the quality improved vastly under the new control, the condition of the old plant made it out of the question to render really satisfactory service. The subscribers had been told that the practical remedy for their sorrows was to build a new automatic plant and scrap the old one, and that the Company was doing this with all possible speed. Great things had been promised for the automatic service, and with this hope the public had watched with growing interest the construction of buildings, the digging of the streets, the pulling of the cables through the manholes, and the installation of wall cables and telephones in their houses.

Another powerful influence in developing and maintaining interest in the coming of the automatic telephone had been the educational campaign carried on to instruct both subscribers and non-subscribers in the proper use of the dial instrument. In the weeks immediately preceding the cut-over, Commercial Department agents made visits to the houses of all subscribers to instruct them in dialing and to allow them to hear the dialing, ringing and busy tones. Public demonstration stations were set up in twelve different parts of the city to allow passers-by to practice the use of the automatic,

TABLE I

Work Schedule

Order for Operation

Madrid Cut-over—December 29, 1926

No.	Description	Office	Supervisor	Begin	Finish
				P.M.	P.M.
1	Report men on duty	Hortaleza and Telefonemas	Mr. Hale	7:00	
2	Report ready to change jumpers Telefonema trunks	Hortaleza	"	7:30	
3	Report Traffic releases multiple for three Telefonema trunks	"	Mr. Quinn	8:00	
4	First order to tie down jumpers for Telefonema trunks	"	Mr. Hale	8:00	8:15
5	Report Traffic releases multiple for eight Telefonema trunks	"	Mr. Quinn	10:00	
6	Second order to tie down jumpers for Telefonema trunks	"	Mr. Hale	10:05	10:30
7	Report men on duty	Gran Via	Mr. Ward Mr. Schooneman	10:15	
8	"	Jordan	Mr. Eckstein Mr. Rinkjob	10:15	
9	"	Salamanca	Sr. Marin Mr. Stalder	10:15	
10	Report Power Plant running	Gran Via	Mr. Schooneman	10:30	
11	"	Jordan	Mr. Rinkjob	10:30	
12	"	Salamanca	Mr. Stalder	10:30	
13	Report all men at their positions	Gran Via	Mr. Ward Mr. Schooneman	11:50 11:50	
14	"	Jordan	Mr. Eckstein Mr. Rinkjob	11:50 11:50	
15	"	Salamanca	Sr. Marin Mr. Stalder	11:50 11:50	
16	"	Hortaleza	Mr. Hale	11:50	
17	Report Traffic Release	All	Mr. Quinn	11:55	
				Midnight	A.M.
18	Order to Cut Multiple Cables	Jordan	Mr. Eckstein	12:00	12:05
19	"	Salamanca	Sr. Marin	12:00	12:05
20	Order to Cut Jumpers	Gran Via	Mr. Ward	12:00	12:05
21	Wait for Reports on 18, 19 and 20 before next orders				
				A.M.	
22	Order to remove fibres from cut-off relays	Gran Via	Mr. Schooneman	12:07	12:20
23	"	Jordan	Mr. Rinkjob	12:07	12:20
24	"	Salamanca	Mr. Stalder	12:07	12:20
25	Order to shut down manual	Jordan	Mr. Eckstein	1:00	
26	"	Salamanca	Sr. Marin	1:00	

Additional Work Schedule

No.	Description	Office	Supervisor	Begin	Finish
				A.M.	A.M.
1	Order to connect trunks for 04 Service	Hortaleza	Mr. Hale	12:15	1:30
2	Third order to tie down jumpers for Telefonema trunks	"	"	12:15	12:25
3	Report Replaced fibres cut-off relays	Jordan	Mr. Rinkjob	12:45	
4	"	Salamanca	Mr. Stalder	12:45	
5	"	Gran Via	Mr. Schooneman	1:15	
6	Report Removed temporary jumpers automatic M.D.F.	"	Mr. Ward	3:00	
7	"	Jordan	Mr. Eckstein	7:00	
8	"	Salamanca	Sr. Marin	7:00	
9	Report Test of Inter-Office trunks	Gran Via	Mr. Caldwell	7:00	
10	"	Jordan	"	7:00	
11	"	Salamanca	"	7:00	
12	Order to shut down manual	Mayor	Sr. Garrion	10:00	

Note:—A.M. refers to the morning of December 30, 1926.

and at these places instruction was given to 41,477 persons. At the same time, 22,074 illustrated folders and 6,422 copies of the Company's magazine were passed out to visitors at these demonstration booths. Moving pictures showing the use of the automatic telephone were run in the principal theatres, large advertisements were published in the newspapers, cards and posters were displayed in public places, and subscribers were circularized.

While all this publicity undoubtedly stimulated curiosity to try the new service, at the same time it served the helpful purpose of familiarizing the people with the use of the automatic telephone. The effort and expense represented by this educational campaign proved to be well justified by the low subscribers' error factor manifested immediately after the cut-over, and that steadily declined in the months that followed.

It is not extravagant to say that the automatic service has more than lived up to the fondest expectations of the people of Madrid. To meet the general demand for additional facilities, the Company proceeded immediately after the cut-over to extend the plant in all parts of the city. Work was started on the first of the year 1927 upon a new exchange building, to be known as Delicias, to serve a portion of the area now belonging to the Gran Via office. Meanwhile, the installation of additional equipment was started in the three existing exchanges, so that by the end of 1927 Gran Via had approximately 10,000 lines, Salamanca 8,000 and Jordan 7,000, thus giving Madrid an increase from 17,000 to 25,000 lines in the first year following the cut-over. The first 5,000-line unit of the Delicias exchange will come into service in 1928. Additions of 3,000 lines in Jordan, 2,000 in Salamanca and 2,000 in Delicias, and the first 5,000-line unit of the permanent Gran Via exchange, will be cut in before the close of 1929, bringing the automatic plant facilities of Madrid up to 42,000 lines.

Modern Wall Telephone Type.

A new long distance switchboard will be installed in the permanent Gran Via building in 1929. Meanwhile, in the Hortaleza exchange are the 28-position No. 2001 Toll Board; the 16-position No. 2001-D Board which, with certain modifications, is handling the suburban service as well as the P.B.X. calls of the Company; a 10-position information desk; and a 10-position recording desk.

The 6-position complaint desk is in the provisional Gran Via exchange, and there is located in a building on the Puerta del Sol a 28-position board where are handled the "telefonemas," or written messages that are handed in by the public for transmission by telephone to all parts of Spain.

Outside plant extensions are varied and correspondingly large. The programme includes laying 23,000 metres of fibre conduit; pulling 21,725 metres of underground cable, containing 39,492,000 metres of conductors; installing 52,900 metres of wall cable, representing 6,669,550 metres of conductors; stringing 5,375 metres of aerial cable, with a total conductor length of 1,373,500 metres; planting 150 poles and placing 6,420 metres of drop cable.

La Transformation du Réseau Téléphonique de Paris en Automatique*

Par G. POCHOLLE

Ingénieur des Télégraphes

La téléphonie automatique se généralise rapidement dans le monde entier. La France n'est pas en retard sur ce point et, actuellement, toutes les installations neuves de moyenne et grande importance sont équipées en automatique.

L'article ci-dessous—qui fait suite aux études que nous avons publiées précédemment sous la signature de M. Cornet, Ingénieur en chef des Postes et Télégraphes—est consacré au réseau de Paris, dont la transformation en automatique est en voie de réalisation.

L'auteur, après quelques considérations d'ordre général, décrit les appareils qui seront employés à Paris, puis expose la façon dont seront résolus quelques-uns des problèmes que pose la transformation d'un réseau téléphonique de l'importance de celui de Paris: organisation générale du réseau, liaisons entre centraux automatiques et centraux manuels, liaisons entre Paris et les réseaux limitrophes atteints directement sans passer par l'interurbain.

Il montre enfin les avantages considérables qui seront obtenus par le téléphone automatique: rapidité, sûreté, facilités d'entretien et souplesse d'exploitation.

La Téléphonie Automatique à Paris

LA TECHNIQUE des réseaux urbains de moyenne et grande importance est définitivement orientée vers l'automatique; introduit pour la première fois en France dans un réseau public à Nice, en 1913, l'automatique a été successivement installé à Angers, Marseille, Orléans, Dieppe, Vichy, Le Hâvre, Montpellier. Les installations de Lyon, Bordeaux, Rennes, Troyes, Nantes, Fontainebleau, Colmar sont en cours de montage; la transformation de tous les autres réseaux importants est prévue dans un avenir très rapproché; enfin celle de Paris, à l'étude depuis plusieurs années, a été décidée en octobre dernier, et les travaux d'installation vont commencer incessamment.

NÉCESSITÉ D'UNE TRANSFORMATION PROGRESSIVE

Le réseau de Paris compte actuellement 150 000 abonnés environ, répartis en une trentaine de séries: Gutenberg, Central, Louvre, etc. . . . , à chacune desquelles correspond un central téléphonique ou « multiple »; le trafic est très intense, si on le compare à celui de la plupart des grands réseaux étrangers: 1 500 000 communications urbaines par jour, soit environ 250 000 communications à l'heure chargée, avec des pointes de près de 20 000 communications simultanées. La transformation d'un réseau aussi important ne saurait être instantanée. D'une part, aucun constructeur ne serait capable de livrer en une seule fois le matériel nécessaire. D'autre part, la substitution générale et instantanée de centraux automatiques aux centraux manuels existants exigerait le dédoublement de toutes les installations. L'opération serait, de plus, désastreuse au point de vue financier: un grand nombre de centraux manuels sont tout récents et en excellent état de service; désaffecter ces centraux alors qu'ils sont loin d'être amortis serait gaspiller les deniers de l'État.

CONSÉQUENCES

La transformation du réseau de Paris sera échelonnée sur une dizaine d'années environ; lorsqu'elle sera entièrement terminée, le réseau comptera vraisemblablement près de 400 000 abonnés (l'accroissement du réseau, très rapide, suit une loi à peu près exponentielle au taux d'environ 10% par an).

Le programme de transformation prévoit l'équipement de 40 000 lignes par an en moyenne; les premiers bureaux automatiques seront les suivants:

Carnot (rue Guyot): 6 000 lignes équipées en 1928, complété à 10 000 en 1929;

Diderot (avenue Daumesnil): 10 000 lignes équipées en 1929;

Gobelins (boulevard de Port-Royal): 10 000 lignes équipées en 1929;

Vaugirard (rue Jobbé-Duval): 8 000 lignes équipées en 1929;

Trudaine (rue de Navarin): 10 000 lignes équipées en 1929.

La coexistence, pendant toute la période transitoire, de centraux manuels et de centraux automatiques nécessite des installations spéciales destinées à écouler le trafic manuel vers automatique et automatique vers manuel; ces installations comprennent des *indicateurs d'appels* d'une part, des *positions semi-B* et *claviers de sélection directe* d'autre part.

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La transformation en automatique nécessite, de plus, des installations spéciales destinées à écouler le trafic échangé entre le réseau urbain et les réseaux limitrophes de la banlieue de Paris; ces installations, analogues aux précédentes, seront rassemblées dans des *centres de transit.*

Établissement d'une Communication en Réseau Automatique

Le poste d'abonné en réseau automatique diffère des postes actuels par l'adjonction du *cadran d'appel* (fig. 1).

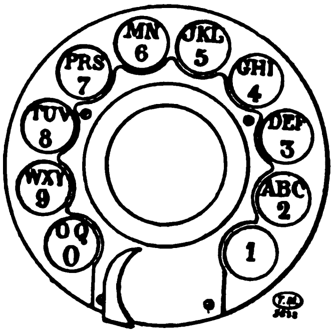

Fig. 1—Dispositif du cadran d'appel de Paris

DEMANDE DE COMMUNICATION EN RÉSEAU AUTOMATIQUE

Pour demander une communication en réseau automatique, décrocher l'appareil et porter le récepteur à l'oreille. Une tonalité spéciale, dite *signal de transmission* (tonalité continue de même hauteur que le retour d'appel), indique que les organes du central sont en mesure de recevoir l'appel (cette tonalité parvient au demandeur une seconde et demie environ après le décrochage). Envoyer alors avec le cadran successivement chacun des signes, lettre ou chiffre, composant le numéro de l'abonné demandé (pour demander par exemple Ségur 46–62, envoyer SEG 46–62).

L'envoi d'une lettre ou d'un chiffre se fait très simplement de la façon suivante: enfoncer l'index dans le trou correspondant à cette lettre ou à ce chiffre; tourner le disque mobile jusqu'à ce que le doigt soit arrêté par la butée fixe; lâcher alors le cadran, qui revient de lui-même à sa position de repos. L'envoi d'un chiffre dure en moyenne une seconde et demie et l'envoi d'un appel complet, à Paris, environ dix secondes. Le demandeur perçoit le *retour d'appel* ou le *signal d'occupation* aussitôt la *sélection* terminée, soit en moyenne treize à quatorze secondes après le début de la manœuvre du cadran. Cette durée est légèrement augmentée dans le cas où le demandé est relié à un bureau manuel, mais n'excède pas alors vingt à vingt-cinq secondes.

AIGUILLAGE DE LA COMMUNICATION

La manœuvre précédente a pour effet de relier la ligne du demandeur à celle du demandé de la façon suivante.

L'abonné décrochant son appareil, sa ligne se marque appellante au central. Elle est prise aussitôt par un *chercheur de lignes* ou *chercheur primaire*, puis à la suite par un *chercheur d'appels* ou *chercheur secondaire*. Ces chercheurs sont des organes de présélection, destinés à concentrer le trafic et à le répartir également sur l'ensemble de l'installation automatique. La présélection étant effectuée, la ligne de l'abonné est prolongée par un *chercheur d'enregistreurs* vers un *enregistreur* qui, aussitôt connecté, envoie à l'abonné demandeur le signal de transmission.

L'abonné demandeur manœuvrant son cadran, celui-ci transmet au central des *impulsions*; une impulsion est un signal télégraphique composé d'une rupture de 0,066 seconde et d'une fermeture de 0,033 seconde. A chaque lettre ou chiffre envoyé par l'abonné correspond un *train d'impulsions*, composé d'autant d'impulsions élémentaires qu'il existe d'unités dans le chiffre envoyé ou dans le chiffre inscrit sur le cadran à côté de la lettre envoyée (le chiffre 0 correspond à 10). Chaque train d'impulsions est reçu dans l'enregistreur sur un commutateur à 10 positions;

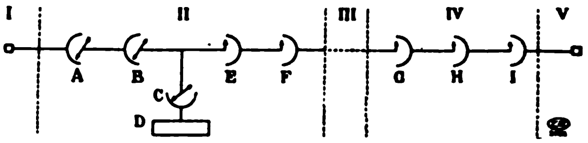

Fig. 2—Diagramme d'établissement d'une communication entre deux abonnés reliés à des bureaux automatiques différents

I, Poste et ligne de l'abonné demandeur;—II, Bureau automatique de départ;—III, Ligne auxiliaire;—IV, Bureau automatique d'arrivée;—V, Poste et ligne de l'abonné demandé.

II.—A, Chercheur primaire ou de lignes;—B, Chercheur secondaire ou d'appels;—C, Chercheur d'enregistreurs;—D, Enregistreur-traducteur;—E, Sélecteur primaire (de bureau);—F, Sélecteur secondaire (de bureau).

IV.—G, Sélecteur tertiaire (numérique);—H, Sélecteur quaternaire (numérique); —I, Sélecteur final (numérique).

à la fin de l'envoi, le numéro complet est en quelque sorte matérialisé par l'orientation de ces commutateurs. Le rôle de l'abonné est alors terminé.

L'enregistreur ayant reçu le numéro demandé commande et contrôle le mouvement et l'arrêt en position convenable d'une série d'organes aiguilleurs ou *sélecteurs*. Le diagramme de la figure 2 montre l'établissement d'une communication en réseau complètement automatique; les sélecteurs primaire et secondaire aiguillent la communication vers le bureau auquel est relié l'abonné demandé; les sélecteurs tertiaire, quaternaire et final placés dans le bureau d'arrivée aiguillent la communication jusqu'à la ligne de l'abonné demandé.

Aussitôt les appareils orientés en position convenable, le demandé est *sonné* ou signalé *occupé*; le demandeur perçoit le retour d'appel ou le signal d'occupation. L'enregistreur, dont le rôle est terminé, se libère. Les organes de sélection reviennent en position de repos lorsque les abonnés raccrochent à la fin de la communication.

Nous verrons plus loin comment les choses se passent lorsque, en période de transformation du réseau, l'un des deux abonnés est encore relié à un central manuel.

Les Appareils Automatiques

Le réseau de Paris sera équipé avec le matériel du type dit *Rotary*, décrit antérieurement par notre Revue.[1] Les appareils ayant subi depuis cette date quelques modifications, nous croyons utile de les décrire à nouveau ici, en indiquant les raisons de ces modifications et les avantages qui en résultent.

CHERCHEURS

Les chercheurs de lignes (fig. 3 à 5), d'appels et d'enregistreurs sont du même type. Un chercheur se compose:

1° D'un *banc de contacts* fixe semi-cylindrique de 100 points (50 points pour le chercheur d'enregistreur);

2° D'un *chariot porte-balais* mobile autour de l'axe du banc. Le chariot porte deux jeux de balais diamétralement opposés montés électriquement en parallèle. Lorsque le banc est à 50

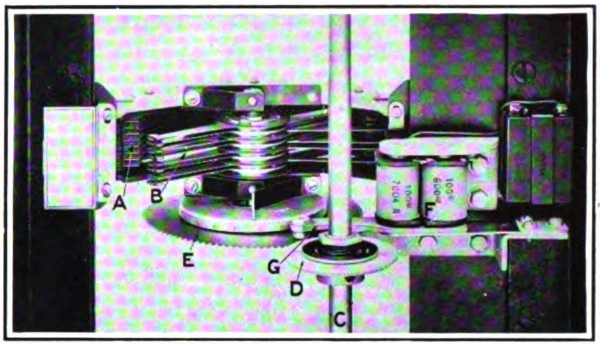

Fig. 3—Vue d'un chercheur
A, Banc de contacts;—B, Balais;—C, Arbre en rotation permanente;—D, Roue motrice;—E, Roue entraînée flexible;—F, Electro d'embrayage;—G, Armature de l'électro d'embrayage.

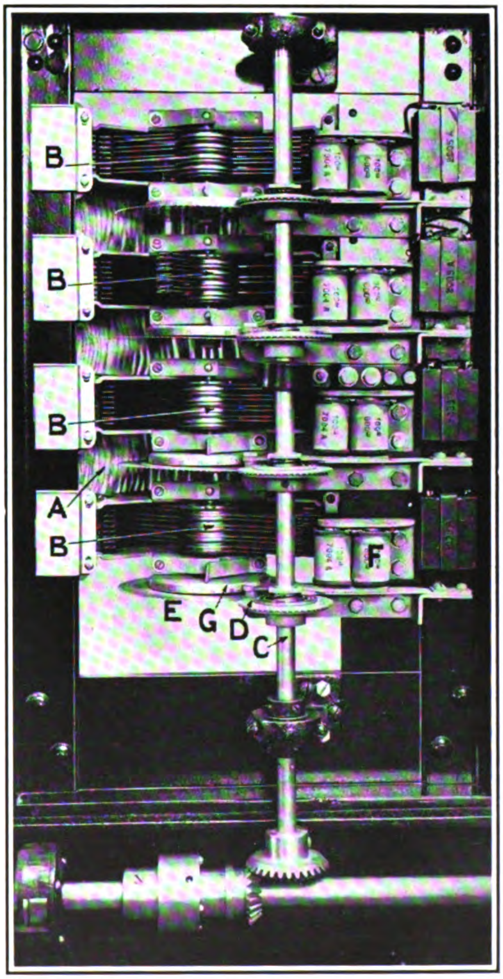

Fig. 4—Vue avant d'une baie de chercheurs
A, Multipliage en câbles-rubans;—B, Chariots porte-balais;—C, Arbre en rotation permanente;—D, Roue motrice;—E, Roue entraînée flexible;—F, Electro d'embrayage;—G, Tambour numéroté.

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[1] Voir La Technique Moderne, t. XIV, n° 12 (15 nov. 1922), p. 490.

points, les deux jeux explorent successivement les mêmes broches; lorsque le banc est à 100 points, les deux jeux sont décalés de la moitié de l'intervalle compris entre deux balais et explorent deux séries de 50 jeux de broches, elles-mêmes décalées l'une par rapport à l'autre de la même quantité.

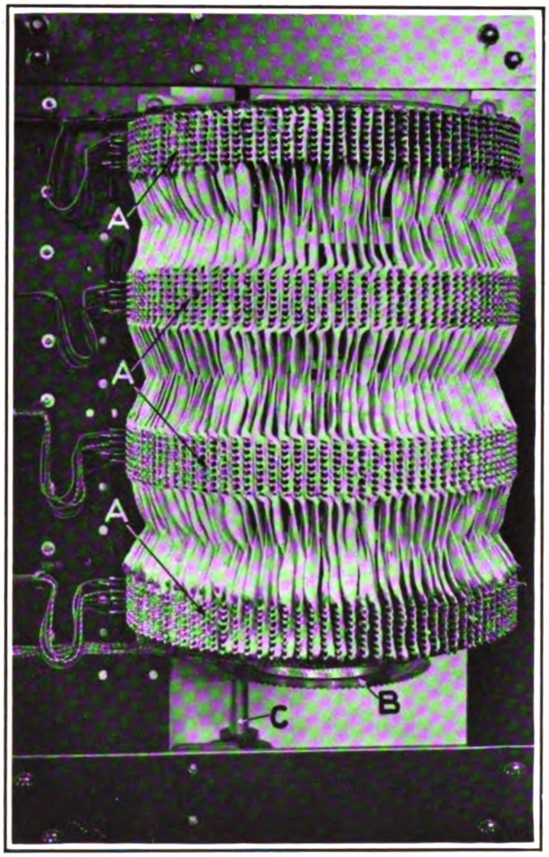

Fig. 5—Vue arrière d'une baie de chercheurs
A, Broches de soudure reliées par les câbles-rubans;—B, Roue flexible du chercheur inférieur;—C, Arbre en rotation permanente.

Cet appareil diffère assez sensiblement de l'ancien chercheur Rotary. Le champ de recherche a été porté de 60 à 100 lignes afin de réduire le nombre d'organes nécessaires à l'écoulement du trafic. D'autre part, le mode d'entraînement a été modifié: l'embrayage magnétique a été remplacé par un engrenage à roues dentées; la roue motrice, calée sur l'arbre, est animée d'un mouvement de rotation continu; la roue entraînée, solidaire du chariot porte-balais, est flexible; au repos, l'armature de l'électro d'embrayage maintient écartée de la roue motrice la roue dentée flexible en lui imprimant une déformation élastique. Ce dispositif permet de déterminer très exactement les tolérances admissibles: en particulier, le glissement au démarrage est au plus égal au pas de l'engrenage; le circuit magnétique de l'électro d'embrayage en position de travail peut comporter un entrefer: la rémanence n'est plus à craindre et le glissement à l'arrêt est pratiquement nul.

Sélecteurs de groupes

Le sélecteur (fig. 6 à 8) se compose:

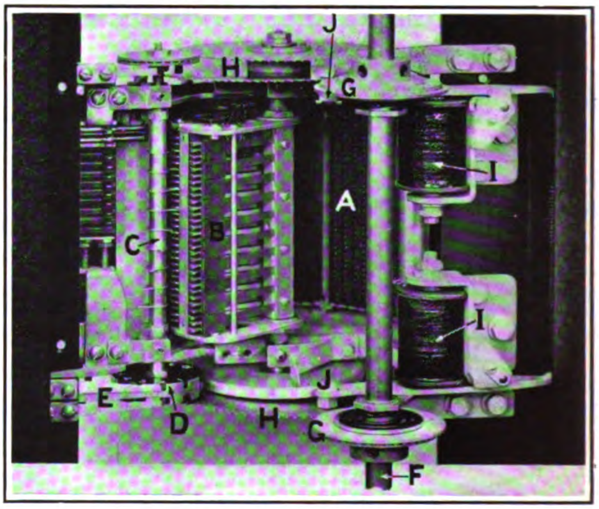

Fig. 6—Vue d'un sélecteur de groupe
A, Banc de contacts;—B, Chariot porte-balais;—C, Déclencheur de balais;—D, Interrupteur d'impulsions inverses et de centrage;—E, Frotteurs de l'interrupteur;—F, Arbre en rotation permanente;—G, G, Roues motrices;—H, H, Roues entraînées flexibles;—I, I, Electros d'embrayage;—J. J, Armatures des électros d'embrayage.

1° D'un *banc de contacts* fixe, semi-cylindrique, de 300 points disposés en 10 niveaux de 30 points;

2° D'un *chariot porte-balais*, mobile autour de l'axe du banc; le chariot porte 10 jeux de balais—un par niveau—tous montés électriquement en parallèle; un jeu de balais ne peut venir en contact avec le banc que s'il a été préalablement déclenché; un rouleau libre l'enclenche à nouveau lors du retour au repos;

3° D'un *arbre déclencheur de balais*, mobile autour d'un axe parallèle au précédent. Cet arbre porte dix ergots—un par niveau—disposés en hélice (le pas de l'hélice est de 30° par niveau environ) et un interrupteur d'impulsions inverses.

Le fonctionnement de l'appareil est le suivant: sous le contrôle de l'enregistreur qui reçoit les impulsions inverses produites par l'interrupteur, l'arbre déclencheur de balais s'oriente en position convenable; le chariot porte-balais démarre alors, le jeu de balais convenable est déclenché au passage devant l'ergot du déclencheur de balais et explore au cours de la rotation du chariot les 30 lignes du niveau correspondant.

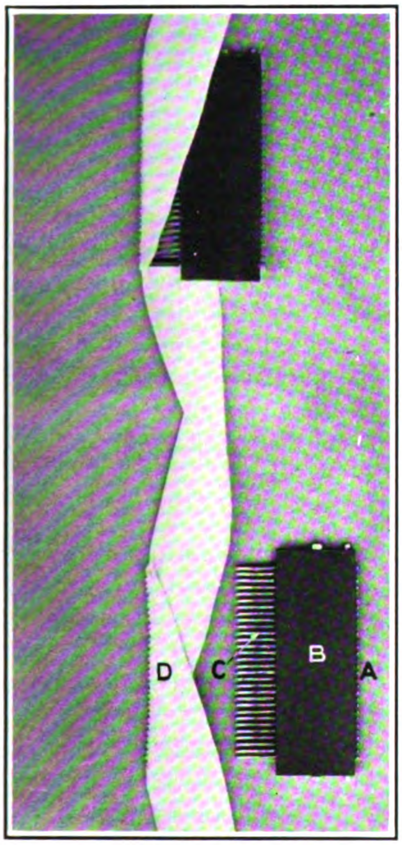

Fig. 7—Vue d'un câble-ruban pour baie de sélecteurs A, Broches de contact;—B, Isolant moulé;—C, Broches de soudure;—D, Câble-ruban.

Cet appareil se distingue de l'ancien sélecteur Rotary par l'augmentation du champ de sélection (30 points par niveau au lieu de 20). L'entraînement est analogue à celui du chercheur précédemment décrit (engrenages à roue entraînée flexible). De plus, l'interrupteur d'impulsions inverses a été complètement modifié: au lieu d'un galet commandant des ressorts de contacts, il se compose (fig. 9) d'un disque en matière isolante dont la surface cylindrique porte une bague conductrice convenablement découpée sur laquelle viennent frotter trois balais: un balai central, point commun, relié à la terre en permanence, un balai d'impulsions inverses et un balai de centrage. Ce dispositif a permis d'augmenter les coefficients de sécurité des circuits; l'emploi combiné de l'embrayage à roues dentées et du balai de centrage a permis de supprimer l'électro-frein tout en augmentant la précision de l'arrêt.

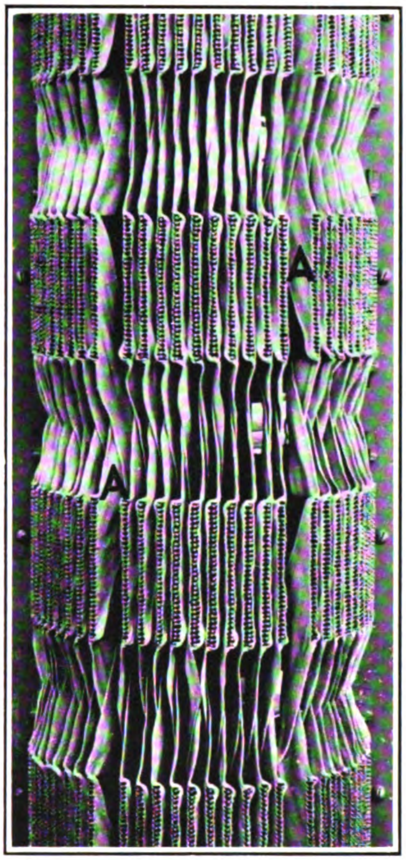

Fig. 8—Vue arrière d'une baie de sélecteurs A, Câbles-rubans

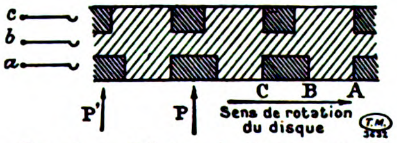

Fig. 9. — Schéma de l'interrupteur d'impulsions inverses.

▨, Plaque conductrice; — ▧, Isolant; — *a*, Balai relié au fil d'impulsions inverses; — *b*, Balai relié à la terre; — *c*, Balai de centrage relié à l'électro d'embrayage; — A, B, Impulsion de court-circuit; — B, C, Impulsion de fermeture; — A, C, Impulsion complète; — P, P', Positions d'arrêt.

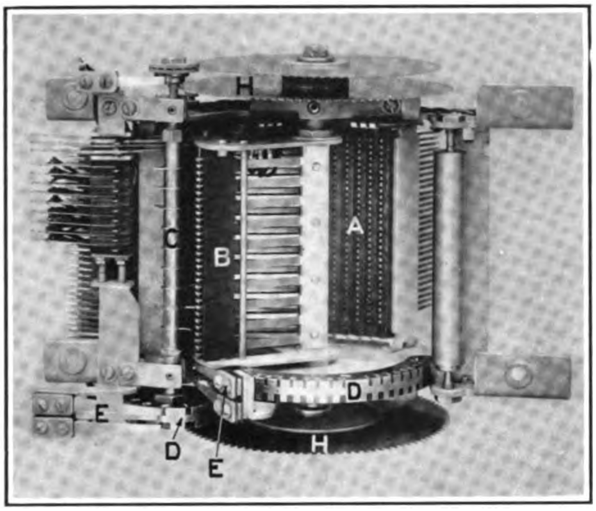

Fig. 10—Vue d'un sélecteur final (non monté sur baie) A, Banc de contacts;—B, Chariot porte-balais;—C, Déclencheur de balais;—D, Interrupteur d'impulsions inverses et de centrage;—E, E', Frotteurs de l'interrupteur; —H, H, Roues entraînées flexibles.

Sélecteurs finals

Le sélecteur final (fig. 10) est identique au sélecteur de groupe, sauf en ce qui concerne:

1° Le champ de broches, qui est à 200 points (un bloc supplémentaire de 100 points peut être ajouté dans certains cas particuliers);

2° Le chariot porte-balais, qui porte un interrupteur d'impulsions inverses analogue à celui de l'arbre déclencheur de balais.

Combineurs

Le combineur (fig. 11 et 12) qui sera employé à Paris diffère profondément de l'ancien combineur Rotary à axe vertical. Le nouveau combineur, dit à axe horizontal, déjà en service dans plusieurs installations, se compose:

1° D'un axe à section carrée sur lequel sont calées de 8 à 24 cames (non compris la came conductrice);

2° De balais fixes, au nombre de 4 par came. Chaque came se compose d'un disque isolant sur les deux faces duquel sont fixées des plaques conductrices convenablement découpées. Les deux plaques d'une came sont reliées électriquement; deux cames voisines peuvent être reliées par une bague conductrice.

L'entraînement est également produit par un engrenage à roue entraînée flexible. La came conductrice ou came A est à becs relevés de façon à augmenter la précision de l'arrêt. Il peut exister 18 positions d'arrêt, de 20° en 20°. Ce combineur permet d'effectuer, au cours de l'engagement d'un appareil, toutes commutations possibles entre 96 fils pris par groupes de 4, 8, 12, etc. . . . Il a permis de donner une très grande souplesse aux circuits, tout en supprimant un certain nombre de relais et en augmentant les coefficients de sécurité (fig. 13 et 14).

Les Circuits

Les circuits qui seront réalisés à Paris ne diffèrent pas dans leur ensemble des circuits Rotary qui ont été décrits bien souvent au cours de ces dernières années. L'emploi du combineur type horizontal et les modifications apportées aux appareils ont permis d'augmenter sensiblement les coefficients de sécurité.

Certains circuits ont dû être adaptés aux problèmes particuliers posés par la transformation du réseau. Nous allons exposer brièvement

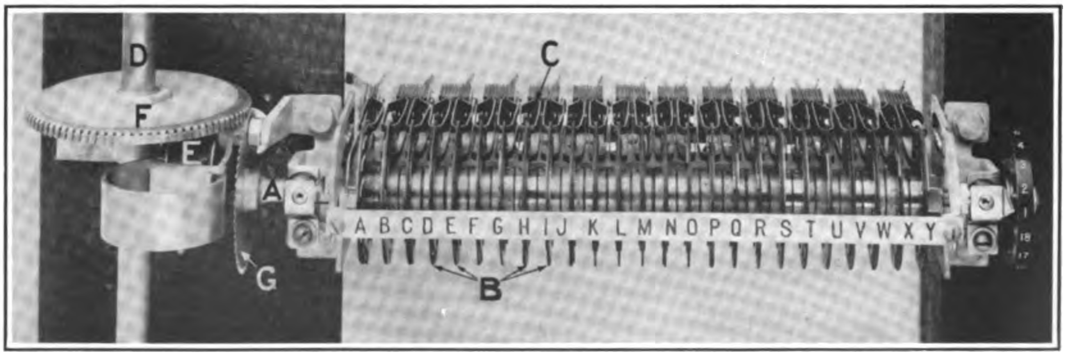

Fig. 11—Vue d'un combineur
A. Axe;—B, Cames;—C, Frotteurs fixes;—D, Arbre en rotation permanente;—E, Electro d'embrayage;—F, Roue motrice;—G, Roue entraînée flexible.

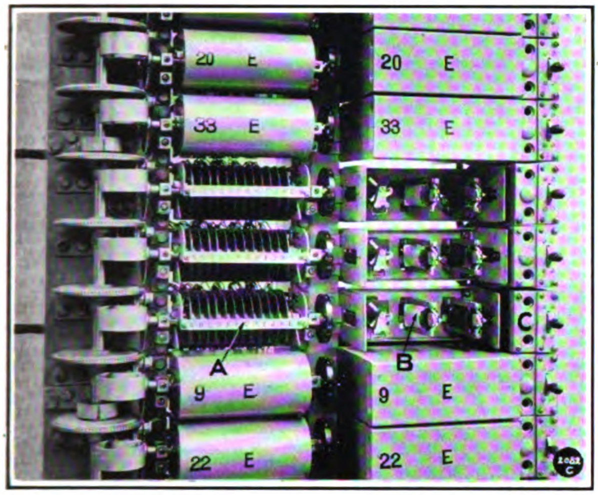

Fig. 12—Détail d'une baie de combineurs et relais
A, Combineurs;—B, Relais;—C, Clé, lampes et jacks d'essais.

le principe du circuit le plus important, celui du *traducteur*.

Traduction.—Le système automatique de Paris sera, comme ceux de Londres et de New-York, caractérisé par l'emploi de la traduction. L'étude générale d'un grand réseau automatique montre qu'il est extrêmement intéressant de ne pas lier le dispositif des voies employées pour l'acheminement des communications à la façon dont l'appel est effectué, c'est-à-dire aux indicatifs des différents bureaux.

Nous avons dit plus haut qu'un appel au cadran est fait sous la forme SEG 46–62 par exemple. L'indicatif SEG reçu dans l'enregistreur doit permettre à cet organe d'aiguiller la communication, par un nombre convenable d'étages de sélection, vers le bureau demandé, Ségur en l'espèce. L'indicatif à trois lettres correspond à l'envoi de trois trains d'impulsions, donc à la commande de trois commutateurs d'enregistrement; si l'on employait pour effectuer la sélection les procédés habituels, le bureau demandé serait atteint obligatoirement par l'intermédiaire de trois sélecteurs et de trois seulement. Or, il est intéressant de pouvoir disposer à volonté du nombre des étages de sélection, ainsi que du niveau à atteindre sur chacun des sélecteurs employés.

Le *traducteur* fait partie de l'enregistreur; c'est un commutateur qui possède autant de positions d'arrêt que de directions possibles (une par bureau ou service spécial); l'indicatif étant reçu, le traducteur démarre et vient s'arrêter dans la position correspondant à la direction demandée (fig. 15). Il contrôle alors la sélection en liaison avec les commutateurs d'inversion; son circuit est disposé de telle sorte que, suivant la direction demandée, il peut assurer une, deux, trois ou quatre sélections successives avant d'arriver au bureau destinataire: il « traduit » ainsi l'indicatif envoyé par l'abonné en un nombre de 1 à 4 chiffres.

Un répartiteur de traduction, placé entre les bancs des commutateurs enregistreurs de récep-

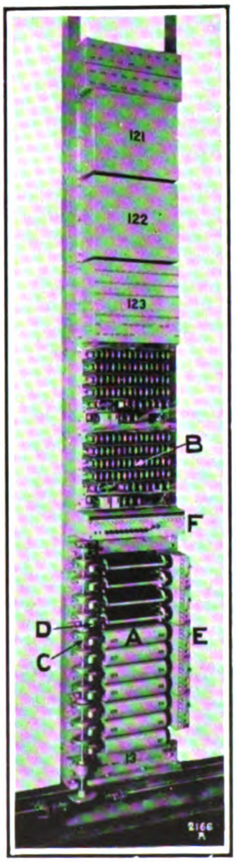

Fig. 13—*Vue d'ensemble*

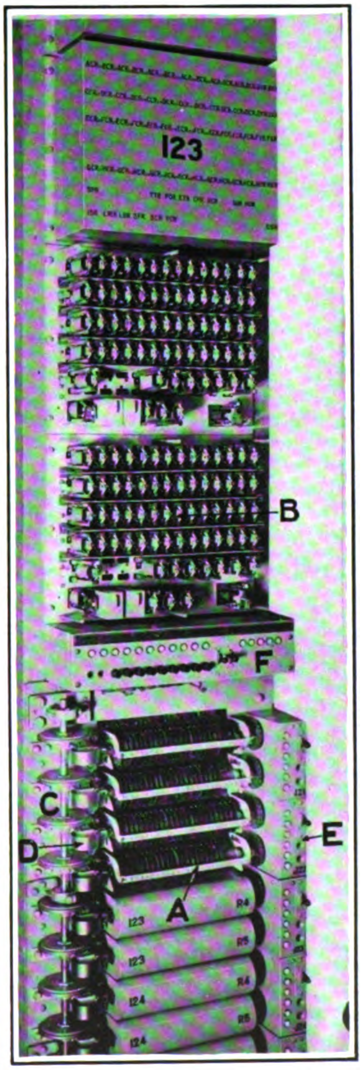

Fig. 14—*Détails*

Fig. 13 et 14.—Vues d'ensemble et détails d'une baie d'enregistreur à relais (type Nantes)
A, Combineurs;—B, Relais;—C, Arbre en rotation permanente;—D, Dispositif d'embrayage des combineurs; —E, Lampes de contrôle, clés, et jacks d'essais;—F, Lampes et clés de contrôle.

tion et d'inversion et le banc du traducteur, permet de changer à volonté le tracé de l'acheminement de la communication.

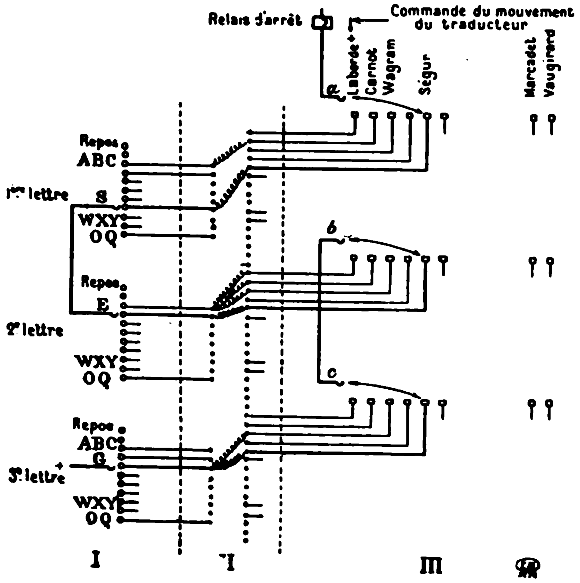

Fig. 15—Schéma du circuit du traducteur. Réception I, Organes enregistrant l'indicatif envoyé pear l'abonné; —II, Répartiteur de traduction côté réception;—III, Traducteur;—*a*, *b*, *c*, Balais de réception du traducteur. On a supposé l'indicatif SEG reçu et le traducteur en position de repos. Le traducteur démarre et s'arrête sur les broches correspondant à la direction Ségur. Un deuxième répartiteur relie les balais d'inversion du traducteur aux organes enregistrant les impulsions inverses. Un balai spécial détermine pour chaque direction le nombre d'étages de sélection.

La traduction donne à l'automatique une souplesse remarquable. Elle permet d'établir un tracé rationnel des lignes auxiliaires entre bureaux en assurant à celles-ci l'utilisation optimum. Elle permet, en cas d'incident sur un faisceau de lignes, de détourner très rapidement les communications en faisant des mutations dans le répartiteur de traduction. Elle permet de généraliser l'emploi extrêmement avantageux des sélecteurs tandem. Enfin, les séries d'un grand réseau manuel que l'on transforme en automatique peuvent conserver leurs appellations nominales, alors que les séries d'un grand réseau équipé sans traduction doivent être désignées à l'annuaire par des nombres; on évite ainsi un changement général de numérotation, et l'annuaire peut conserver sa forme habituelle: l'abonné Ségur 46–62 par exemple sera inscrit sous la forme SEGur 46–62.

Liaisons Automatique Vers Manuel

Lorsqu'un abonné automatique demande un abonné manuel, tout se passe pour le demandeur comme si le demandé était lui-même automatique. L'abonné ayant envoyé son appel, l'indicatif oriente le traducteur qui aiguille l'appel sur une ligne auxiliaire se rendant au bureau d'arrivée. Mais les quatre chiffres envoyés par l'abonné, au lieu de commander la mise en place de sélecteurs numériques, actionnent des commutateurs, d'ailleurs équivalant à ces sélecteurs en ce qui concerne le contrôle effectué par l'enregistreur. Ces commutateurs commandent l'allumage de lampes qui font apparaître le numéro demandé en chiffres lumineux sur une position dite à *indicateur d'appels*, indiquant ainsi à l'opératrice qui dessert cette position la connexion à établir.

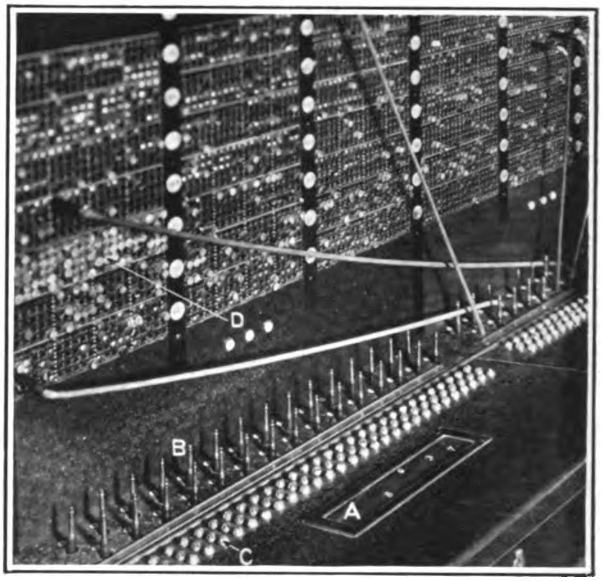

Fig. 16—Vue d'une position à indicateur d'appel sur groupe d'arrivée
A, Panneau lumineux;—B, Monocordes;—C, Lampes de contrôle (appel, occupation, fin);—D, Jacks généraux.

Ici deux solutions sont possibles:

1° Indicateurs d'appels sur groupes d'arrivée (fig. 16 et 17)

L'opératrice de la position à indicateur d'appels est une opératrice d'arrivée du bureau destinataire; elle dispose du multiplage des lignes d'abonnés. La jonction prise par l'appel aboutit devant elle sur un monocorde qui se signale appelant par l'allumage d'une lampe; l'opératrice saisit ce monocorde et, après avoir fait le test, l'enfonce dans le jack général de l'abonné demandé.

Cette méthode est la plus logique et la moins coûteuse; mais elle n'est pas toujours applicable, car certains bureaux manuels ne se prêtent pas à l'installation de ces indicateurs d'appels.

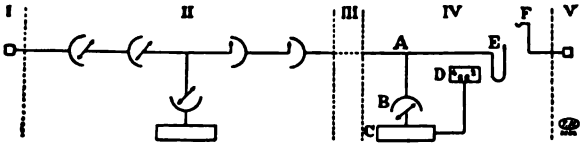

Fig. 17—Diagramme d'établissement d'une communication automatique vers manuel. Indicateur d'appel sur groupe d'arrivée

I, Abonné demandeur;—II, Bureau automatique de départ;—III, Ligne auxiliaire;—IV, Bureau manuel d'arrivée;—V, Abonné demandé.

IV.—A, Ligne axiliaire entrante;—B, Chercheur de jonction;—C, Enregistreur d'indicateur d'appels;—D, Panneau lumineux d'indicateur d'appel;—E, Monocorde;—F, Jack général de l'abonné demandé.

2° INDICATEURS D'APPELS TANDEM SANS MONOCORDES (FIG. 18)

L'opératrice de la position à indicateur d'appels est placée en *tandem* entre le bureau de départ et le bureau d'arrivée. Les jonctions ne sont que représentées devant elle par des jeux de lampes et vont aboutir sur les monocordes d'une position d'arrivée ordinaire du bureau destinataire. La jonction prise par l'appel se signale par l'allumage d'une lampe à l'opératrice tandem; celle-ci entre en relation par ligne d'ordres avec l'opératrice d'arrivée et lui indique le numéro de l'abonné demandé et la jonction appelante; l'opératrice d'arrivée saisit le monocorde correspondant et l'enfonce dans le jack général de l'abonné demandé.

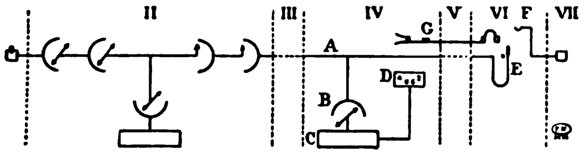

Fig. 18—Diagramme d'établissement d'une communication automatique vers manuel. Indicateur d'appels tandem sans monocorde

I, Abonné demandeur;—II, Bureau automatique de départ;—III, Ligne auxiliaire;—IV, Bureau tandem;—V, Ligne auxiliaire;—VI, Bureau d'arrivée;—VII, Abonné demandé.

IV.—A, Ligne auxiliaire en transit;—B, Chercheur de jonctions;—C, Enregistreur d'indicateur d'appels;—D, Panneau lumineux d'indicateur d'appels.

VI.—E, Monocorde d'arrivée;—F, Jack général de l'abonné demandé.

IV, V et VI.—G, Ligne d'ordres.

Les positions à indicateurs d'appels tandem peuvent être placées en un point quelconque du parcours entre le bureau de départ et le bureau d'arrivée. Il peut être avantageux de les placer, soit dans le bureau automatique de départ, soit dans un bureau intermédiaire, soit dans le bureau manuel d'arrivée.

Liaisons Manuel Vers Automatique

Lorsqu'un abonné manuel demande un abonné automatique, tout se passe pour l'abonné demandeur comme si le demandé était lui-même manuel. L'abonné énonce verbalement à l'opératrice de départ le numéro qu'il demande.

Ici encore, deux solutions sont possibles.

1° SÉLECTION DIRECTE (FIG. 19)

L'opératrice de départ, au lieu de se mettre en relation avec une opératrice d'arrivée par ligne d'ordres, enfonce la fiche d'appel du dicorde dans un *jack individuel* correspondant à la direction demandée; cette manœuvre a pour effet de connecter le jack individuel avec un enregistreur; l'opératrice « tape » alors, sur un clavier de 10 boutons numérotés de 0 à 9, les quatre chiffres du numéro demandé; ces chiffres sont reçus dans l'enregistreur; en même temps, le jack, et avec lui l'enregistreur, se relient à une ligne auxiliaire aboutissant sur un sélecteur du bureau automatique d'arrivée; l'enregistreur contrôle la sélection numérique; lorsque la ligne de l'abonné demandé est atteinte par le sélecteur final, l'abonné demandeur perçoit le retour d'appel ou le signal d'occupation. L'opératrice de

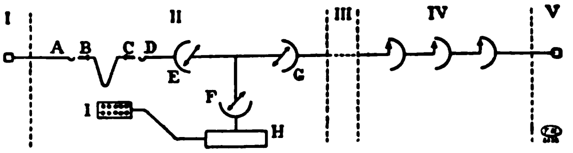

Fig. 19—Diagramme d'établissement d'une communication manuel vers automatique. Sélection directe

I, Abonné demandeur;—II, Bureau manuel de départ;—III, Ligne auxiliaire;—IV, Bureau automatique d'arrivée—V, Abonné demandé.

II.—A, Jack local de l'abonné demandeur;—B, Fiche de réponse;—C, Fiche d'appel;—D, Jack individuel de sélection directe;—E, Chercheur de jack;—F, Chercheur d'enregistreur;—G, Chercheur de jonction;—H, Enregistreur de sélection directe;—I, Clavier de sélection directe.

départ possède la supervision comme dans le cas d'une communication manuelle.

2° Positions semi-B (fig. 20)

L'opératrice de départ traite les communications destinées aux bureaux automatiques comme celles destinées aux bureaux manuels; mais elle se trouve en relation, sur la ligne d'ordre, non avec une opératrice d'arrivée d'un bureau manuel, mais avec une opératrice dite *semi-B* placée en tandem entre le bureau de départ et le bureau d'arrivée; celle-ci possède un clavier sur lequel elle « tape » le numéro demandé; ce numéro est reçu dans un enregistreur qui se comporte dès lors comme un enregistreur de sélection directe; les jonctions sont représentées devant l'opératrice semi-B par des jeux de lampes indiquant l'occupation ou la disponibilité, ce qui lui permet de désigner à l'opératrice de départ le numéro de la ligne auxiliaire à employer.

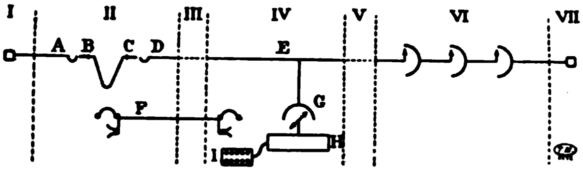

Fig. 20—Diagramme d'établissement d'une communication manuel vers automatique (position semi-B)

I, Abonné demandeur;—II, Bureau manuel de départ;—III, Ligne auxiliaire;—IV, Bureau tandem;—V, Ligne auxiliaire;—VI, Bureau automatique d'arrivée;—VII, Abonné demandé.

II.—A, Jack local de l'abonné demandeur;—B, Fiche de réponse;—C, Fiche d'appel;—D, Jack de ligne auxiliaire;—E, Ligne auxiliaire en transit;—F, Ligne d'ordres;—G, Chercheur de jonction;—H, Enregistreur semi-B;—I, Clavier semi-B.

Les positions semi-B peuvent être placées en un point quelconque du parcours entre le bureau de départ et le bureau d'arrivée. Il peut être avantageux de les placer, soit dans le bureau manuel de départ, soit dans un bureau intermédiaire, soit dans le bureau automatique d'arrivée.

Liaisons Avec les Réseaux Limitrophes

Les liaisons des bureaux automatiques de Paris avec les bureaux manuels de banlieue seront assurées dans les deux sens par des installations analogues aux précédentes.

Toutefois, on ne peut relier tous les bureaux de Paris à tous les bureaux de banlieue par des lignes directes; on emploie par suite des positions tandem à indicateurs d'appels ou semi-B qui, non seulement transforment un appel automatique en appel manuel ou inversement, mais encore aiguillent les communications vers les différentes directions possibles. Ces positions tandem sont donc pourvues de monocordes.

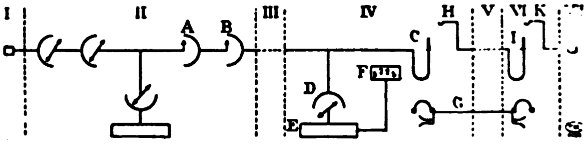

Fig. 21—Diagramme d'établissement d'une communication automatique vers banlieue. Indicateur d'appels tandem avec monocorde

I, Abonné demandeur;—II, Bureau automatique de départ;—III, Ligne auxiliaire;—IV, Centre de transit;—V, Circuit Paris vers banlieue;—VI, Bureau manuel de banlieue;—VII, Abonné demandé.

II.—A, Sélecteur primaire;—B, Sélecteur secondaire de banlieue.

IV.—C, Monocorde de position tandem;—D, Chercheur de jonction;—E, Enregistreur d'indicateur d'appels;—F, Panneau lumineux d'indicateur d'appels;—G, Ligne d'ordre;— H, Jack de circuit.

VI.—I, Monocorde de groupe d'arrivée;—K, Jack général de l'abonné demandé.

1° Dans le sens bureau automatique de Paris vers bureau manuel de banlieue (voir fig. 21), on emploie des ***positions tandem à indicateurs d'appels avec monocordes.*** Les lignes venant des bureaux automatiques arrivent sur des monocordes, et l'opératrice tandem aiguille la communication vers l'un quelconque des bureaux de banlieue qu'elle dessert en enfonçant le monocorde dans le jack de la ligne auxiliaire qui lui est désignée par l'opératrice d'arrivée.

2° Dans le sens bureau manuel de banlieue vers bureau automatique de Paris (voir fig. 22),

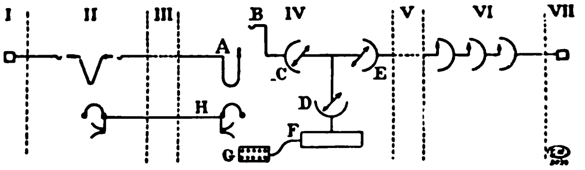

Fig. 22—Diagramme d'établissement d'une communication banlieue vers automatique. Position tandem à sélection directe

I, Abonné demandeur;—II, Bureau manuel de banlieue;—III, Circuit banlieue vers Paris;—IV, Centre de transit;—V, Ligne auxiliaire;—VI, Bureau automatique d'arrivée;—VII, Abonné demandé.

IV.—A, Monocorde de position tandem;—B, Jack individuel de sélection directe;—C, Chercheur de jack;—D, Chercheur d'enregistreur;—E, Chercheur de jonction,—F, Enregistreur;—G, Clavier de sélection directe;—H; Ligne d'ordres.

on emploie des *positions tandem à sélection directe*. Les jonctions venant des bureaux manuels aboutissent sur des monocordes et l'opératrice tandem, à laquelle l'opératrice de départ indique le bureau et le numéro de l'abonné demandé, dispose de jacks de sélection directe pour assurer l'aiguillage des communications vers l'un quelconque des bureaux automatiques de Paris.

L'étude générale des liaisons entre Paris et sa banlieue conduit à concentrer ces positions—tandem à indicateurs d'appels avec monocordes et tandem à sélection directe—dans des *centres de transit*, au nombre de quatre. A chaque centre de transit correspond un secteur de banlieue (nord-ouest, nord-est, sud-ouest et sud-est), le centre de transit nord-ouest, par exemple, desservant toutes les communications échangées dans les deux sens entre tous les abonnés automatiques de Paris et tous les abonnés de la banlieue nord-ouest.

Les centres de transit pourront dans la suite devenir automatiques au fur et à mesure de la mise en automatique des réseaux de banlieue. Les positions tandem seront remplacées par des sélecteurs tandem qui aiguilleront les communications Paris-automatique vers Banlieue-automatique et vice versa par voie complètement automatique.

Avantages de l'Automatique

La technique automatique, avons-nous dit, se généralise rapidement, non seulement en France, mais dans le monde entier. C'est là le signe d'avantages incontestables par rapport à la téléphonie manuelle. Nous allons énumérer ci-dessous les principaux, en remarquant que, s'ils ne peuvent évidemment jouer pleinement qu'en réseau complètement automatique, ils se manifesteront progressivement à mesure de la transformation.

RAPIDITÉ ET SÛRETÉ

La communication est établie en moins de quinze secondes, ceci à n'importe quelle heure du jour ou de la nuit, aussi bien au moment des pointes—le nombre des organes étant calculé pour écouler à une probabilité extrêmement dure le trafic maximum—qu'aux heures creuses, les organes étant évidemment toujours à la disposition des abonnés.

Les risques d'erreurs sont réduits au minimum, et ne peuvent plus provenir que d'une inattention de l'abonné.

Les fausses manœuvres (connexions en double, tests erronés, etc.) sont rigoureusement impossibles, par suite de verrouillages électriques effectués par les circuits.

Les coupures intempestives sont complètement éliminées; la communication toute entière une fois établie est placée sous le seul contrôle des abonnés; elle est coupée par eux-mêmes lorsqu'ils raccrochent leurs appareils.

L'appel au cadran est une opération extrêmement simple, qui évite les pertes de temps.

La rupture est immédiate: dès que le demandeur a raccroché, tous les organes sont libérés, et il peut demander immédiatement une nouvelle communication (il suffit pratiquement d'abaisser à fond le crochet commutateur pendant une seconde au plus).

FACILITÉS D'EXPLOITATION ET D'ENTRETIEN

L'automatique permet de résoudre aisément un grand nombre de problèmes que la téléphonie manuelle n'aborde que difficilement. L'organisation générale d'un réseau peut, en automatique, être conçue de façon à utiliser au maximum tous les organes et toutes les lignes.

Par la mise en œuvre de circuits d'essais systématiques, l'état des installations est connu à chaque instant, des essais préventifs complets permettent de réduire au minimum le nombre des dérangements et d'assurer un service tout à fait remarquable.

Enfin, si le prix de revient d'une installation est plus élevé en automatique qu'en manuel, les frais de personnel sont considérablement diminués, de sorte que l'exploitation automatique est sensiblement moins onéreuse que l'exploitation manuelle.

Ernest Penny

In Memoriam
Ernest Penny

It is with deep regret that we have to record the death, on October 26th, in Madrid, of Mr. George Ernest Reginald Penny, Chief Engineer of the Standard Electrica S.A.

Mr. Penny joined the Engineering Department of the London House in 1904. He was given charge of the Apparatus Division in 1911 and appointed Assistant Chief Engineer in 1919. Three years later he was transferred to the European Engineering Department and was thus one of its early members. During the War he was prominently associated with the activities of the London House in the solution of vital problems concerning the development of new types of war material, particularly in the invention, development and manufacture of hydrophone equipment.

On several occasions, during his career, he was called upon to make foreign journeys. In 1918 he visited America to demonstrate hydrophone equipments to the American Naval Authorities. During 1920 he spent many months in the Straits Settlements and in India, studying means for the protection of telephone apparatus against deterioration. In 1923 he again visited America, this time for the study of machine switching systems. The years 1924–1926 were spent chiefly with the Australian House in Sydney, where he gave general assistance in telephone engineering matters.

His early association with the Company, his wide and varied experience, as well as his high personal and professional abilities fitted him for a prominent position, and insured his success in all the varied phases of his career. His many friends within and without the Company remember him as a man of the highest integrity, with broad views and simple tastes. He was a strict disciplinarian but he exercised his discipline firstly upon himself, seeking the result as regards others in the effects of his own example, and he established for himself a standard of efficiency that often imposed on him a burden beyond the powers and conscientiousness of most men. He possessed an essentially honest mind; he was not concerned to find the answer to a problem along any line of predisposition, but he tackled the matter with the sole desire to find truth and a real solution. Possessed of a mind clear and precise, and a power of expression easy and effective, his judgment upon controversial questions always demanded respect, while his cheerful energy and good temper made him singularly successful in composing differences of opinion. His administrative experience had taught him to seek solutions of problems by reasoning from general principles. Nevertheless, when necessity arose, he would face the details—often complex and difficult—with dogged perseverance, until he arrived at a practical result. On his foreign travels he had frequently to face tasks of this character single-handed.

From his earliest years he was a lover of outdoor sport. His hobby was photography and he brought back from his foreign journeys many good examples of his triumphs in that direction. His friends will remember that he was a good musician and a skillful player of the piano and organ. Those who knew him best were aware that his principal home study was the Bible, and that it to him was something real that inspired him in his daily work.

He married early in 1914 Miss Ethel Setterfield of Eastbourne, England, who went with him on his travels, and who supported him alike in his sports, his music and his work, both at home and abroad.

Early in last October, when in Madrid, he was troubled with gastric disorder which rapidly developed into an obscure fever suspected to be typhoid. Double pneumonia supervened and although everything was done to afford relief, the end came suddenly. His death at the age of only forty-one years renders the loss particularly sad. It will be deplored by his innumerable friends, both within and without the circle of his professional activities, particularly those of the International Telephone and Telegraph System.

The International Conference on High Tension Systems

By G. H. NASH

Chief Engineer, Standard Telephones and Cables, Ltd.

BEFORE the Great War there were few international organisations dealing with engineering problems. Each country had its own technical institutions at which papers were read and problems were discussed, but there was little direct exchange of views between engineers of different countries. There was, of course, the International Electrotechnical Commission, usually referred to as the "I.E.C.," founded in 1906, but this existed for standardisation in matters where practice had become stabilised rather than for discussion of current problems.

Since the War, there has been an increasing sense of the value of discussion of common technical problems from the international standpoint. This has resulted in the holding of a series of international conferences, particularly in connection with problems of power generation and transmission, so that at present there is some risk of undue multiplication of conferences with consequent overlapping of agenda. One of the earliest and most successful of these is the International Conference on High Tension Systems.

At the end of January, 1921, as a result of a conversation between M. Bauer, Director of the Swiss Society for the Transmission and Distribution of Electricity, and M. Aubry, Chief Engineer of the Compagnie Générale d'Électricité in Paris, M. Tribot Laspière, Secretary of the Union des Syndicate de l'Électricité, had the idea of organising a conference which would bring together the engineers of the principal countries concerned with the development and distribution of electrical energy. His project was approved, and the Union thereupon suggested to foreign engineering associations interested in this work that a Conference should be held in Paris. The proposal was welcomed, and the first Conference was held in November, 1921.

The object was to allow of the joint study of all technical problems relating to the construction and operation of large high tension systems. It was definitely understood that only technical problems would be dealt with. Problems affecting legislation, or the import or export of power would not be considered, as these had political aspects with which a private assembly was not able to deal. To maintain this private character it was agreed also that the Conference should not include government representatives, and that if engineers in the service of any government took part in the Conference they would do so in their personal capacity and not as official delegates.

In order that work undertaken by the Conference might not overlap in any way that of the I.E.C., the proposition was discussed with M. Mailloux and M. Le Maistre, then respectively, President and Secretary of the I.E.C. It was agreed that there need be no interference between the objects of the two Conferences. The I.E.C. existed mainly for international standardisation; the object of the new Conference was to effect an exchange of ideas on methods of construction and operation not yet ripe for standardisation. The discussions would, therefore, be confined to a single field and would cover practical and industrial matters as well as those which were mainly scientific. The Conference might, however, make recommendations to the I.E.C. on certain subjects on which general agreement had been reached. With this understanding the I.E.C. not only did not oppose the new Conference, but helped considerably in launching it. The President, Dr. Mailloux, in particular, did a considerable amount of work in order to make it a success.

Professional associations of different countries were invited to form National Committees which might nominate official delegates to the Conference. At the same time other representatives both from operating and manufacturing interests in those countries were invited to take part as free members. As Standard Telephones and Cables, Ltd., was interested in power transmission by high-tension cable, as well as in communication between stations and in remote control of switch-gear, Mr. T. N. Riley, Chief Cable Engineer, attended the Conferences.

First Conference

At the first Conference, held in November, 1921, twelve countries participated, represented by forty-seven official delegates; in addition, a number of free members attended. The official language used in the discussions was either French or English and interpreters were present to translate remarks made during the discussion. At the first Conference about sixty-four papers were read covering:

1. Description of existing or projected high tension systems
2. Operation of central stations
3. Construction of lines
4. Sub-stations
5. Technical operation and protection
6. Communication between stations

At the end of the Conference a resolution was passed expressing the opinion that the reports and discussions had served a very useful purpose and that further Conferences should be held from time to time.

Second Conference

The second Conference took place at the end of November, 1923. Twenty countries were represented by eighty-five official delegates, the total number of visitors from abroad being one hundred and forty-three as against fifty-three on the first occasion. The number of papers read was reduced to forty-nine, as the first Conference had been somewhat overloaded and discussion handicapped. The general programme was similar to that of 1921 except that certain subjects had been noted for special study. These were:

Construction of very high tension lines
Construction and operation of open air sub-stations
Choice of transmitting pressures
High tension cables
International regulations for high voltage lines
Education of the public concerning the risks of high voltage lines

In order to cover the ground thoroughly, one delegate was appointed "rapporteur" in connection with each of these subjects and was charged with the duty of collecting information on the practice of each country and arranging for its presentation to the Conference by separate papers or in a combined report.

Visits to installations were arranged in connection with the Conference.

Third Conference

The third Conference was held in June, 1925, the scope being slightly widened in order to include the generation of electricity. Twenty-seven countries were represented, the total number of representatives from abroad numbering two hundred and twenty-six. Ninety-nine papers were presented in three main groups:

1. Generation
2. Construction and installation of lines
3. Operation of systems

At this Conference as in the two previous ones, discussion was considerably handicapped by the fact that a number of papers were sent in too late to be presented at the meeting, and it was agreed that, at future conferences, arrangements should be made to have papers ready in time. Steps were taken to establish an agreed international model for statistics of production, transmission and distribution, so that economic results in different countries might be more easily compared. Recommendations were also made to the I.E.C. to press forward the establishment of an international agreement on the methods of testing oils and electrical machinery.

Fourth Conference

The fourth Conference was held at the end of June, 1927. Twenty-eight countries were represented, Germany having been added since her admission to the League of Nations. Seventy-five papers were presented, divided into the same three groups as in 1925.

Figure 1 shows a view from the platform of one of the meetings. Amongst the delegates will be noted Dr. A. E. Kennelly near the lantern, Dr. J. B. Whitehead at the door, Messrs. Sonnenfeld and Konstantinovaky, who are associated with the Kabelfabrik A. G. Bratislava on the right of the third row. Figure 2 shows a view of the platform during a discussion on insulating oils.

The subject of high-tension cables is steadily increasing in importance and on this occasion no fewer than nine of the papers presented dealt therewith, the discussion overlapping into the following session of the Conference. Broadly speaking, these papers fell into three groups dealing with, (*a*) the influence of occluded air and moisture, (*b*) the best physical structure, and (*c*) the method of testing which will give a satisfactory indication of reliability in service. A considerable amount of research work on these points has been carried out during the last two years at the high-tension research laboratory of Standard Telephones and Cables, Ltd., at Woolwich.

In the course of the discussion, Mr. Riley pointed out that most of the deterioration tests put forward were chemical, and that the research work carried out by Standard Telephones and Cables, Ltd., in connection with oils for cable insulation had shown that a much more sensitive measure of deterioration could be obtained by electrical measurements of the change of power-factor of the oil. The discussion also elicited that, in the past, oil refining had been directed rather to producing a lubricant than to perfecting a dielectric.

In general, the data put forward by other experimenters confirmed the results already obtained at Woolwich, London.

The importance of adequate drying and impregnation in a modern high-voltage cable is now recognised, but the detailed methods of securing these results and the material structure favouring them, is not so well appreciated.

It is generally agreed that the type of three-core cable having an equipotential sheath round each core is likely to give the best results in operation. On the method of testing there is not equal agreement. It is recognised that cables may pass the routine excess pressure test and yet fail in service after weeks or even months, and engineers are at present divided into two schools of thought. On the one hand, it is considered that a test of the power factor-voltage characteristic before and after heating on load, affords the

Figure 1—At the Fourth Conference—View from the Platform

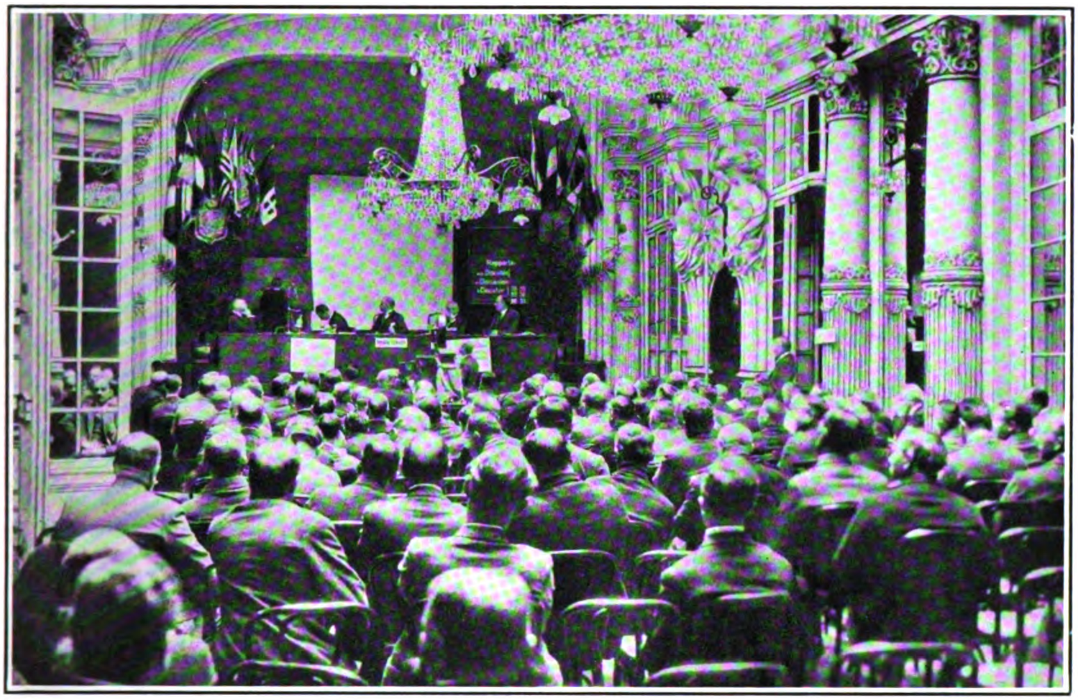

Figure 2—A Meeting of the Fourth Conference

best indication of whether the cable will be stable in service. On the other, it is maintained that the time for which a cable will withstand a given pressure has a definite relation to the pressure, and it is possible to determine by an extra high pressure short period test what lower pressure the cable will withstand indefinitely. A committee was formed to formulate proposals for acquiring further evidence on this point.

As the length of transmission lines increases, communication between stations by telephone cable in the neighbourhood of the high tension lines becomes more costly and less satisfactory in operation, and there is an increasing tendency towards the use of carrier current communication making use of the power lines themselves. A number of the papers which were read described the various systems which have been tried. In the discussion, attention was directed to the extreme difficulty in such systems of eliminating parasitic noises arising either from the power lines themselves or from external static discharges.

Such noises not only disturb speech but might lead to false calls if the disturbance happened to be of the same nature as that to which apparatus is designed to respond. In many systems installed at the present day, telephone communication is only satisfactory because the operators know more or less the nature of the communication to be received.

During the conference, visits were arranged to high-voltage plants of interest in the neighbourhood of Paris, in particular to the generating station of Gennefilliers from which power is transmitted by 60,000 volt underground cable, and to the 1,000,000 volt laboratory of the Porcelain Factory at Ivry.

These conferences are incomplete without the social functions which afford members a better opportunity of getting into personal touch with their confreres in other countries than is possible in the more rigid circumstances of controlled discussion. The organisation of these gatherings by our French hosts left nothing to be desired and, although the weather was adverse for the greater part of the week, during the one open air function—a garden party held at the fine old residence given by the Rothschild family to the French nation—the sun shone brilliantly.

The Calculagraph

By H. C. DILSIZIAN

Export Department, International Standard Electric Corporation

THE Calculagraph as designed for telephone service was developed to provide an accurate means of computing the duration of long distance conversations. Its true value to the telephone world can be appreciated best by a brief survey of its predecessors.

Before the advent of the Calculagraph, it was the practice in many exchanges to record the start and finish of toll calls by glancing at a wall clock and writing down the time in longhand on tickets provided for the purpose. These tickets were taken to clerks who computed the elapsed time by subtracting one record from the other. A check for accuracy of computation was made by a second group of clerks. Careful tests showed that, because of the human element involved in this practice, approximately 20 percent of the records contained inaccuracies of one minute or more. In practically every instance these errors were in favor of the subscriber.

The use of time stamps for recording the start and finish of conversations was a decided step forward. While the human element was thereby partially eliminated, the actual computation of elapsed time was performed by clerks and the precautions taken could not prevent errors.

Another instrument used was the stop watch, which indicated the exact duration of a call by pressing a button at the start and finish of a conversation. The stop watch, however, presented several serious disadvantages. With it the operator could handle only one call at a time and the actual record had to be made in longhand, which involved loss of time for the operator, and impaired the general efficiency of the service.

The problem, therefore, was to overcome the weak points of these methods and devise a machine which would embody their respective advantages. It was required in effect that the desirable features of time stamps, namely, the accurate recording of the start and finish of a conversation, be combined with the accuracy of the stop watch in indicating elapsed time; that provision be made for recording this elapsed time; and, finally, that the machine desired should be capable of handling, practically simultaneously, not only one, but an unlimited number of calls. The solution to the problem was the Calculagraph.

Within a comparatively brief period telephone companies in the United States and other countries realized the value of the Calculagraph, and today, with a few rare exceptions, it is used in connection with all long distance calls in the United States and Canada.

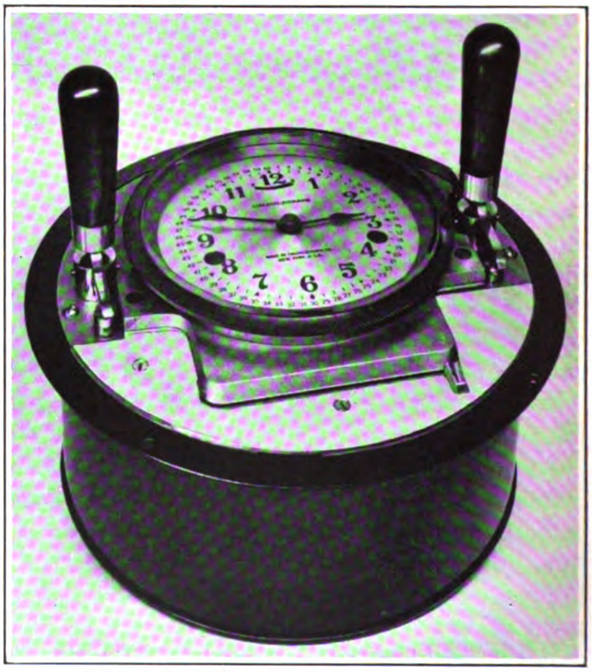

Figure 1—The Calculagraph.

The Calculagraph (Figure 1), which is manufactured exclusively by the Calculagraph Company of Harrison, New Jersey, is either a spring driven or an electrically actuated time recorder, which prints the date and time of the day similar to other time stamps, but it also has the exclusive feature of automatically computing and printing the length of time elapsed between the start and finish of an operation. Its special construction enables it to record accurately the duration of an unlimited number of toll calls without regard to the consecutive order of starting. In practice a Calculagraph usually is placed between two operators (Figure 2) who employ it on all toll calls handled by them for recording the start and the finish of conversations.

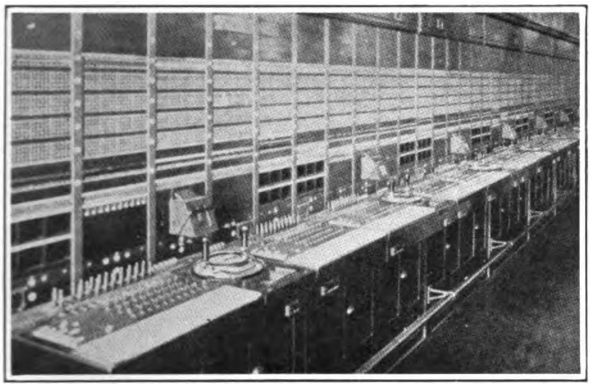

Figure 2—Switchboard with Calculagraphs Placed between Operators' Positions.

At the commencement of a conversation the operator inserts a ticket in the slot of the Calculagraph and moves the right hand lever backward and then forward, as illustrated in Figure 3. The backward movement prints the hour of the day in the form of a clock dial, and immediately below, if desired, the year, month and day. The triangular pointer shown just above "X" in Figure 4 corresponds to the hour hand of the clock; the arrow within the circle, to the minute hand. Thus the record reproduced in the figure indicates that the call was connected on May 5, 1927, at 10:10 A.M. Incidentally, it may be of interest to note that it is necessary to set the date stamp each day; the A.M. and P.M. designations are controlled automatically by the Calculagraph mechanism.

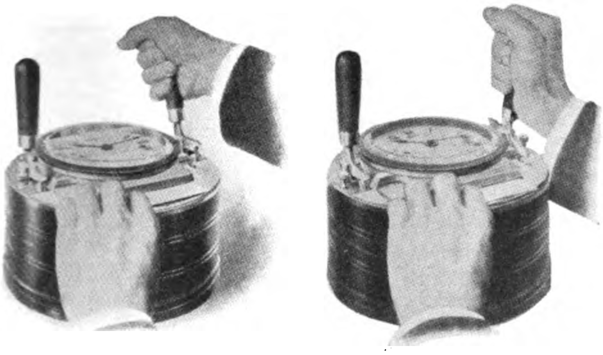

Figure 3—Recording the Start of a Call.

The forward motion of the right hand lever prints the two elapsed time dials, together with the serial number of the machine. After this operation the ticket is withdrawn from the slot, the record at this stage appearing as in Figure 4, and the Calculagraph is ready for stamping tickets for other messages in a similar manner.

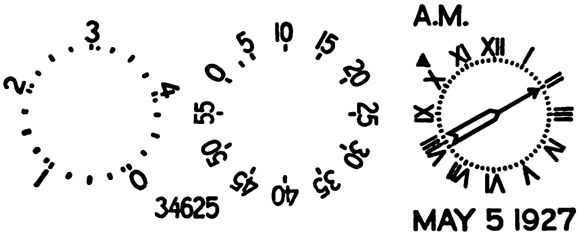

Figure 4—Record of the Start of a Call.

When a call is completed, the ticket covering it is again inserted in the slot of the Calculagraph and the left hand lever is pulled forward. This operation stamps the pointers in the two elapsed time dials imprinted at the start of the call, thereby indicating the elapsed time in minutes and fractions. The completed record appears as illustrated in Figure 5, which shows that the call lasted four minutes.

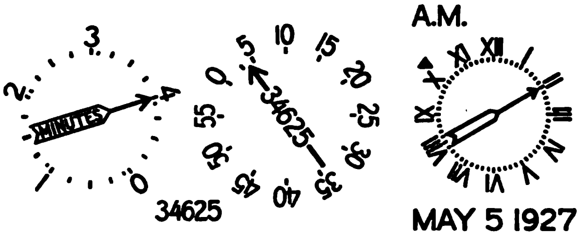

Figure 5—Record of a Completed Call.

To insure the record being started and completed on the same instrument, one of the elapsed time pointers bears the serial number of the machine corresponding to that stamped by the forward motion of the right hand lever at the beginning of the call.

The Calculagraph, in addition to being silent in operation, is of the highest quality, entirely hand assembled, and is given a series of rigid inspections during the course of manufacture. Contrary to what might be expected, the mechanism is extremely simple and rugged.

Each of the two printing dials which record the elapsed time is made of two parts, one part carrying the circle of figures and division marks and the other, the pointer or arrow. The two parts are secured together rotatively by a dowel pin, whereby the arrow always points to the zero mark of the circle. The vertical movement of the parts is independent of each other.

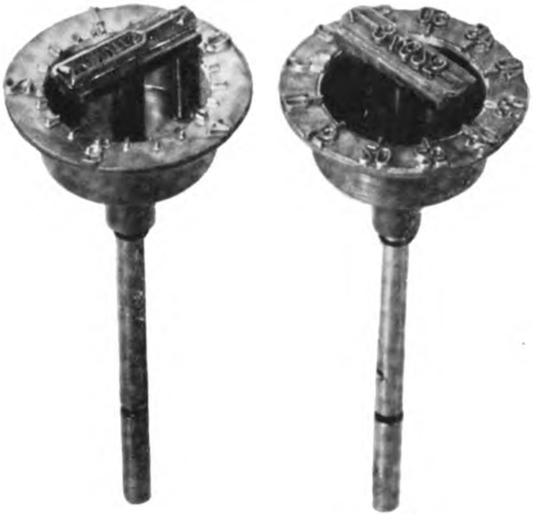

Figure 6—Illustration of Movement of Arrows When Recording the End of a Conversation.

It was mentioned previously that the forward motion of the right hand lever stamps the two elapsed time dials. That operation forces the figures upward and causes them to make an impression on the record, while the arrows, which always point to the zero mark in the circles, remain depressed. When the left hand lever is operated at the end of the conversation, the arrows alone move up, while the figures remain in their original position as indicated in Figure 6.

During the interval between the beginning and the end of a call, the dials containing the circle of Arabic numbers and their associated pointers revolve in unison; and the record card always is inserted into the Calculagraph in the same position. Since the circles are stamped at the beginning of the call and the pointers at the end, the positions of the arrows within the circles indicate the elapsed time or duration of the call. By means of the smaller of the two elapsed time dials the duration of the call may be read accurately without difficulty.

Irrespective of the position of the zero mark when imprinting the larger elapsed time dial at the start of a conversation, it will have travelled 60° at the end of a 10-minute call. If the arrow which travels along with the zero mark is stamped at the conclusion of the call, it will point to "10" on the imprint. In the meantime, if a second call is started immediately after recording the beginning of the previous call and, for example, continues for 6¼ minutes, the zero mark and its associated arrow in the larger circle will have travelled 37½° from the point of origin of the second conversation. The impress of the arrow (Figure 5) made at the conclusion of the call will point a little to the right of "5." At this time the arrow in the smaller dial will have described an arc of 450°, or one complete revolution plus 90°, and will point to 1¼. The "5" of the larger dial plus the 1¼ of the smaller will indicate the exact duration of the call.

It will be noted that the recording of the second call has no bearing whatever on the first. With the Calculagraph any number of calls may be handled and be recorded accurately without regard to sequence.

Loading Coil Cores and Their Magnetic Stability

By FUMIO SHIDA

Engineer, Sumitomo Electric Wire and Cable Works, Ltd.

Being a lecture on the Historical Survey of the Core of Loading Coils and on the Magnetic Stability of the Powdered Iron Core given at the Annual Grand Meeting of the Japanese Institute of Telephone and Telegraph Engineers in September, 1926.

The text has been rendered into English and the whole is given here though not without some apprehension on the part of the author as to its being too verbose for some specialists.

SINCE the publication of Pupin's loading theory on telephone circuits, the efforts made by American engineers in regard to the construction of the core of loading coils is, indeed, beyond our speculation. The writer wishes to review briefly, its historical developments in design and construction and also wishes to give his interpretations of some of the phenomena in and concerning the compressed powdered iron core of loading coils.

The properties which a good loading coil should have and requirements which are very desirable from the standpoint of construction may be itemized as follows:

(1) A number of coils may be used at a given point simultaneously without mutual interference. The coils, therefore, must not have stray magnetic fields.

(2) Electrical loss due to the loading of these coils should be relatively small.

(3) Inductance of the coil should be independent of current. Hence, it should be magnetically stable.

It seems as though the ring form of winding is the only commercial form to conform with the first requirement satisfactorily. In fact, this method remains unchanged although in other respects the coils have undergone various changes and improvements. Figure 3 shows a portion of a coil with the ring form of winding.

To meet the second requirement, it is necessary to make the resistance of the winding of the coil, which is wound to have a certain inductance, very small. In order to minimize the resistance, the coil should have relatively small volume. In order that the coil may be small, a high permeability iron instead of an air or a wood core must be used. When an iron core is used, hysteresis and eddy current losses must be minimized. The use of a fine iron wire for core construction for this purpose is one of the very good methods. In fact, this type of cores has been extensively used until several years ago. In these coils, the size of a wire which is said to have given the best result was as fine as four mils in diameter.

Satisfying the third requirement with the use of an iron core, presents a most difficult task and therefore the greatest effort was made in order to obtain this desirable property. At first, research had been extended to find the iron having the property of magnetic stability against variable magnetic force. The result of the research indicated that hard drawn wire is better in this respect, than soft wire. Therefore in practice, 4-mil wire which has 95 or 60 permeability through hard drawing was concluded to be the best for the core of loading coils and the loading coils with such cores were extensively used for several years.

But since the requirements imposed on telephone circuits became more severe and complicated by superposing the telegraphic current, by constituting phantom circuits or by the additional use of repeaters, the stability of the magnetic property of the core formed with iron wire of this kind was still found not satisfactory.

It seems quite proper to extend the explanation a little further in this regard to make it clear. A hard drawn iron wire core has relatively stable permeability. Yet the state of instability often arises when the core is subjected to a great variation of magnetizing force. When a strong electric current once flows through the loading coil which has the iron core of the described nature, thus subjecting the core, even temporarily, to a strong magnetizing force (this very often occurs in practice, through the superposition of the telegraphic current or through the current used in testing or by lightning discharges), the core will be magnetized, leaving residual magnetism, and hence the core will be exposed to a certain magnetic field intensity. The inductance of the loading coil depends entirely upon the value of the permeability of the core; and the permeability of a core of this kind varies in accordance with the magnetic field intensity to which the core is exposed. Thus, in the above case, the loading coil will have very different inductance from the ordinary case. In this way, a circuit loaded with this form of coil meets impedance irregularity and may show, therefore, a peculiar phenomenon of better operation without than with loading coils. In fact, the trans-continental circuits in the United States were at first loaded with such coils which subsequently were disconnected due to the difficulty just mentioned. These circuits were reloaded with a new provision of air gaps in the cores of the coils to improve the constancy of inductance.[1] This method was patented by an American and is, indeed, an interesting one. The process of providing the gaps may be described as follows:

There is a small gap between windings of the coil. A mechanically operated saw is placed diametrically over these gaps and the core is thus cut, perpendicular to the magnetic flux path, into two similar, semi-circular pieces. A certain thickness of mica is inserted in these gaps and then a brass ring, which is made to fit tightly over the coil, is carefully placed to assure the original ring form. Viewed from the magnetic standpoint, there is a noticeable difference before and after the gaps are provided. It is due to the demagnetizing action within the iron core caused by the surface distribution of magnetism on the four faces at the gaps when the core is magnetized. The result of the demagnetizing action is that it decreases on the one hand, the effective permeability of the core and, on the other hand, it increases the magnetic stability of the core.

Though by providing gaps, the superior magnetic stability of the core can be obtained, it must be admitted that it has short comings such as causing a stray magnetic field and hence, magnetic interference.

Starting from the fact that the polarization of the core brings out the demagnetizing action which in turn, operates to secure the stability of permeability of the core, we may rightly expect that a powdered iron core, when properly constructed, would render the result which is sought. It is readily seen also that this form of core is not only superior and effective in obtaining constancy in effective permeability but also it is better from the standpoint of hysteresis and eddy current losses. In order that this theoretic deduction may be realized, a large amount of energy, time and money were spent in search for a practical powdered iron core and the present compressed powdered iron core is the resultant product of these unfathomed sacrifices.

This research, however, had been begun prior to the World War but the real progress did not take place until the War. With the War, importation of diamond dies for 4-mil wire from Europe stopped. With this as an incentive and spur, research engineers in this field had gone madly (as it was said) after the powdered iron core to replace the 4-mil iron wire core.

This method of getting a constant permeability and hence, a constant inductance, is the best known method at present and all loading coils of recent manufacture are of this type. The writer wishes to outline in the following, its process of manufacture, its magnetic property and its theory.

It was in 1887 when Heaviside asserted that powdered iron, hardened with wax is effective in reducing eddy current. Since this time, many scholars followed him in the study of the powdered iron core but all failed in their attempts, due to the fact that such a core had too small permeability for the purpose under consideration. However, Mr. B. Speed, Engineer of the Western Electric Company, Inc., conceived that if a pure and finely divided iron powder could be insulated and compressed so that the specific gravity was nearly that of the solid iron, it should be possible at low flux densities to obtain permeabilities of the order required for the loading cores. After this, research and efforts for improvements were continued with renewed vigor and prospect, and needless to say that many and marked improvements were made before the Western Electric Company finally succeeded in placing its product in the market.

Let us go back, for a moment, to trace the development. At first, iron powder was obtained by reducing iron oxide in hydrogen. This iron powder was then insulated by means of a suitable film of oxide by reoxidation and a coating of shellac. In order that the particles might not harden into a mass, the powder was continually stirred with shellac solution while being dried. The insulated powder thus obtained was then subjected in a mold, to a pressure of 100,000 pounds per square inch at the surface of the powder, shaping it into the ring form. The compression was found too small and it was later replaced with 200,000 lbs. per square inch.

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[1] These open wire circuits are operated at present without loading coils.

The iron powder obtained from iron oxide, however, was not entirely satisfactory due to the fact that the method was costly and although the particles were hardened to a certain extent, by compression, they were still too soft to give magnetically desirable results. Consequently, improvement along this line was then still urgent. With the suggestion, that if electrolytic iron was pulverized and was used in place of iron oxide, some of the defects might be modified, if not eliminated, research had been carried out with zeal and constancy. The method, which is employed today, was finally found as the result of the efforts made in this research.

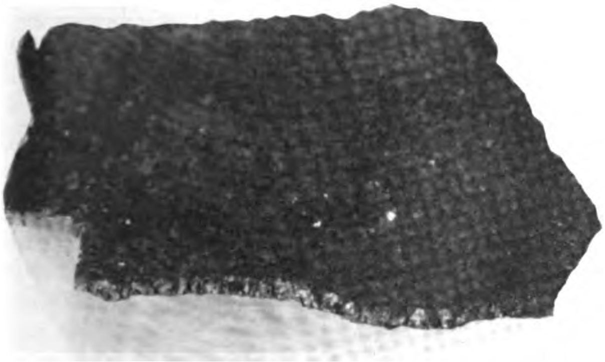

Figure 1—Photograph of a Piece of Iron Peeled off from a Cathode

As for the insulation, all methods of oxidation and shellacking had been carefully attended to and experimented with, but the result was not satisfactory. Mr. J. C. Woodruff found that by mixing the iron powder with flaked zinc, before applying shellac, and rolling the mixture in a drum for a few hours and then removing the zinc by sieving, a very thin and tough insulation of the grains of iron could be obtained. Insulation thus obtained rendered a very satisfactory result, incurring no breakdown after the cores were compressed. This method is the best, the simplest and the most economical one at the present time.

The method of getting electrolytic iron at present is by using a mixture of ferrous sulphate and chloride and ammonium sulphate as electrolyte. As for electrodes, mild steel and polished steel are used for anode and cathode, respectively. The current density is 12 amperes per square foot. The cathodes are removed when the deposit has reached a thickness of 1/8 to 1/4 inch, and are washed in hot water to remove the electrolyte. The deposited iron is then stripped from the cathode sheets and broken up into pieces about an inch square. This material is then pulverized with a ball mill to the size which will pass through an 80-mesh sieve without residue. Figure 1 shows the photograph of a piece of iron peeled off from a cathode and Figure 2 shows the photomicrograph of its cross section (enlarged 100 times).

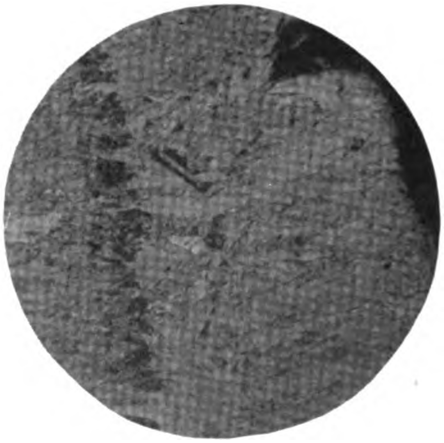

Figure 2—Photomicrograph (Enlarged 100 Times) of Cross Section of Piece of Iron Shown in Figure 1

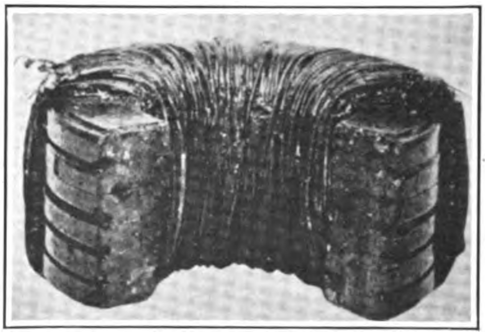

Figure 3—Loading Coil with Ring Form of Winding in Which Part of the Core and Winding Has Been Removed

Pulverized iron is either annealed or unannealed, according to the grade of core required and then compressed into the form. Annealing is done by heating the powder approximately up to 850 degrees centigrade in a cast iron box and is slowly cooled down with the furnace. During this process, the powdered iron forms into lumps so that it is necessary to pulverize it again through a rock crusher. Annealed powder is relatively soft so that when placed under compression, the particles have a tendency to flatten out. Annealing is done in order to utilize this property.

A given weight of the powder is poured through a funnel into a mold on a hydraulic pressing machine (which is similar in construction to a lead sheathing machine) and is molded into a ring form under the pressure of 200,000 pounds per square inch. Immediately after the application of this pressure, the core thus shaped is found heated to the extent that it is almost impossible to touch it with a bare hand. This fact indicates that the compression is giving a ramming effect to the core which is being molded.

The dimensions of these rings differ according to their different uses and requirements, but one of the very common types is $\frac{1}{4}$ inch in thickness with an outer diameter of 4 inches and an inner diameter of $2\frac{1}{2}$ inches. Several of these rings are piled in tiers and wrapped around with cloth, over which is wound the cotton insulated wire as shown in Figure 3.

The Western Electric Company has three standards of cores, namely, Grade *A*, Grade *B* and Grade *C*, all of which are manufactured by the same process, and compressed under the same pressure. These three grades of cores have different magnetic properties owing to the fact that the size of the powder particles and the composition of the powder, as well as its heat treatment, are different in each grade, other things being the same. Grade *A* is the one whose iron powder is passed through an 80-mesh sieve (linear) and is entirely annealed. It has a specific gravity of 7.1 and an effective permeability of approximately 55.

Grade *B* is the same as Grade *A* except that the greater part of the powder used is not annealed; more specifically, 90 percent of it is not annealed and the remaining 10 percent is annealed. Specific gravity of this grade is 6.4 and the effective permeability is 35. Annealed iron is added in order to bring the permeability up to the desired value and also to add somewhat to the mechanical strength of the rings. Grade *C* is manufactured from a mixture of annealed and unannealed powder in the same proportion as Grade *B* but the size of the grain is much smaller; namely, that which passes through a 200-mesh sieve. Specific gravity and permeability in this case are 6.0 and about 25 respectively.

The fact that these three classes of rings have different specific gravities and permeabilities has an important relationship with the theory to be given later. Therefore, the writer wishes to speculate a little further in regard to the cause of such variations. First of all, the fact of the greater specific gravity in Grade *A* than *B* and of *B* than *C*, immediately suggests that the total air spaces still left after compression is least in *A* and greatest in *C*. The reason, as the writer sees it, is that Grade *A* has its powder all annealed and, therefore, it being softer, the percentage of particles which are deformed (flattened) by compression is greater so that intergranular space (as it may be termed) is proportionally less in *A* than *B*. In the case of Grade *B* and *C*, the difference is entirely due to the fineness of the grains of these two standards. With the greater particles, the mass as a whole is further removed from the state of liquid and the compressional force is transmitted mainly in the direction of the force applied so that the particles are quite effectively flattened out, filling up the empty spaces. On the other hand, the mass formed by the finer particles is nearer to the liquid state (doubtless to say that the iron powder under consideration is far from being in a liquid state but one may so consider it in the case of comparison) so that the applied force is transmitted in all directions and the force effective in deforming the particles and filling up the gaps is decreased. It is inferred from this view, that the specific gravity is greater in *B* than *C*. As to the difference in effective permeability, if the relation, which the writer will explain later on, between the effective permeability and the deformation of the grain in the three standards is considered, the case will become self-explanatory.

If the permeability of a core is a constant, the coil which is built with it has a constant inductance, irrespective of current. Furthermore, this inductance can be measured very readily and accurately. If, however, a coil is built with an iron core of variable permeability, the difficulty encountered is not only inductance irregularity but also the complexity of measurement. The following method is one in common use in such a case.

The measurement of inductance of a coil of this kind is always made with alternating current but in this particular case, direct current is superposed on alternating current. Direct current is varied as desired to change the intensity of magnetization and inductance is measured with different field intensities at various intensities of magnetization. These variable inductance data are taken so as to express inductance with corresponding magnetization of the core (internal field intensity) or magnitude of current in the coil. If the variation of inductance is known, permeability at each of these instances can be found.

Such expressions of inductance as stated above have meaning and significance in the case of a solid iron core or a bundled small iron wire core but a core built with iron powder has great ambiguity in such expressions. Yet it is still used occasionally. We find such an example in a discussion on a powdered iron core, given in the Transactions of the A.I.E.E. on page 1340, Vol. XL, 1921. In it, H, B, and μ are expressed similarly as described above. In the same paper, permeability μ and magnetizing force H are said to have been calculated from the following formulas:

$$L = \frac{4\pi N^2 A\mu}{l \times 10^9}, \qquad H_{\max} = \frac{4\pi NI\sqrt{2}}{l \times 10},$$

where L = Inductance in henries
I = Current in amperes (r.m.s.)
H = Magnetizing force in gausses
B = Flux density in gausses
μ = Permeability of core
N = Total number of turns of winding on the core
A = Cross-section of core cm.^{2}
l = Mean length of the magnetic circuit in cm.

Judging from the foregoing discussion, it is clear that these formulas are correctly applicable only where the core of a coil is air, solid iron or bundled iron wire. In these cases, H as expressed in the formula, is in reality the expression of the field intensity in the core. If this value is multiplied by the permeability of the core material, flux density B can be obtained directly. In the case of the powdered iron core, however, the same formula cannot be well applied, since H as given therein exists nowhere in the core due to the fact that it is neither iron nor air but a composition of the two. Within the particles, H is less due to the polar demagnetizing action, and within the air spaces, it is much greater (which will be explained later) than the H as expressed. The permeability μ, which is calculated by substituting measured values of L and known physical factors such as N, A and l in the formula for various values of current densities, is the expression of effective permeability of the powdered core itself. Therefore it has (more or less) some significance. However, from the standpoint of the relationship between this effective permeability and the permeability of electrolytic iron, it has no value.

Indeed, such a composite core as we have here, must be treated as a composition, in order to find any explanation at all for problems such as the following:

(1) Why does effective permeability decrease and stability increase when solid is made into powdered form?

(2) Why does effective permeability increase and stability decrease with increasing deformation by compression while the true permeability of electrolytic iron remains constant?

These problems of effective permeability and stability of the powdered iron core seem to be governed entirely by the polar demagnetizing action of iron particles of which it is composed. In this connection, the writer wishes to state his own belief and oblige himself for criticisms from his readers.

If a piece of iron is brought into a magnetic field of intensity H_0, the magnetic field intensity H within the piece is less than H_0, due to the fact that the magnetic induction of the piece causes polar formation which sets up a counter field within the piece, thereby decreasing the field intensity. This counter field or in other words, demagnetization, is proportional to I, the intensity of magnetization. The proportionality between the two is called the demagnetizing factor and is designated by $\bar{N}$. The value of $\bar{N}$ depends upon the directional shape of the piece, that is, on the length of the piece in the direction of magnetization. The shorter it is, the greater will be the value of $\bar{N}$ or vice versa.

This value for a regular form, such as an ellipsoid of revolution can be calculated. The formula for the calculation and the calculated values of $\bar{N}$ for various values of m (ratio of major to minor axis of ellipsoid of revolution) are as follows:

$$\bar{N} = \frac{4\pi}{m^2-1}\left\{\frac{m}{\sqrt{m^2-1}}\log\left(m+\sqrt{m^2-1}\right)-1\right\}.$$

TABLE

m	0	0.5	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20	∞
$\bar{N}$	12.566	6.586	4.189	2.120	1.328	0.939	0.701	0.538	0.431	0.357	0.295	0.254	0.222	0.196	0.153	0.122	0.100	0.084	0

In the case of irregular form, it is usually difficult to compute $\bar{N}$. However, whatever the shape or form may be, the value of $\bar{N}$ always lies between the two limits of 4π and zero just the same as in the case of an ellipsoid of revolution, so that any shape has a corresponding ellipsoid of revolution having the same $\bar{N}$.

If the above discussion is represented in equations, we have,

$$H = H_0 - \bar{N}I, \tag{1}$$

in which

$$I = \kappa H = \kappa(H_0 - \bar{N}I).$$

Therefore,

$$I = \frac{\kappa H_0}{\bar{N}\kappa + 1}. \tag{2}$$

In this case, an average intensity of magnetic induction, B, within the iron piece is,

$$B = H + 4\pi I. \tag{3}$$

Substituting (1) in (3), we have

$$B = H_0 - \bar{N}I + 4\pi I = H_0 + I(4\pi - \bar{N}). \tag{4}$$

Substituting (2) in (4), we get

$$B = H_0 + \frac{\kappa H_0}{\bar{N}\kappa + 1}(4\pi - \bar{N}) = \frac{H_0(1 + 4\pi\kappa)}{\bar{N}\kappa + 1} = H_0\frac{\mu}{\bar{N}\kappa + 1}. \tag{5}$$

Again,

$$B = \mu H = H_0\frac{\mu}{\bar{N}\kappa + 1}.$$

Therefore,

$$H = \frac{H_0}{\bar{N}\kappa + 1}, \tag{6}$$

where H_0 = Original field intensity
H = Actual field intensity within the piece of iron
I = Intensity of magnetization
$\bar{N}$ = Demagnetizing factor of the piece
κ, μ = Susceptibility and permeability of the piece material, respectively

Since the powdered iron core under discussion is the case in which fine iron powder is located in a magnetic field, the magnetic induction in each particle can be represented by formula (5).

In the case of a loading coil, uniform magnetic field intensity H_0 is,

$$H_0 = \frac{4\pi Ni\sqrt{2}}{l \times 10}. \tag{7}$$

Therefore, a mean magnetic induction B in each particle is

$$B = \frac{4\pi Ni\sqrt{2}}{l \times 10} \times \frac{\mu}{\bar{N}\kappa + 1}. \tag{8}$$

and

$$L = \frac{4\pi Ni\sqrt{2}}{l \times 10} \times \frac{\mu}{\bar{N}\kappa + 1} \times \frac{NA}{i\sqrt{2}} \times 10^{-8} = \frac{4\pi N^2A}{l \times 10^9} \times \frac{\mu}{\bar{N}\kappa + 1}, \tag{9}$$

where L = Inductance in henries
i = Current in amperes
H = Magnetizing force in gausses
B = Magnetic induction or flux density in gausses
μ = Permeability of electrolytic iron
κ = Susceptibility of electrolytic iron
N = Total number of turns of winding on the core
A = Cross-section of core in cm^2
l = Mean length of the magnetic circuit in cm.
$\bar{N}$ = Demagnetizing factor of iron powder

Examining formula (9), we find the term, $\mu/(\bar{N}\kappa + 1)$, which is equivalent to permeability μ in the case of a closed magnetic circuit. In a case such as we have here, where the core is formed by iron powder, it is necessary to use this term, which may be called an apparent permeability, instead of the ordinary permeability μ of the iron. In the discussion of the powdered iron core in the A.I.E.E. Transactions, this term is represented by simple μ and is called effective permeability.

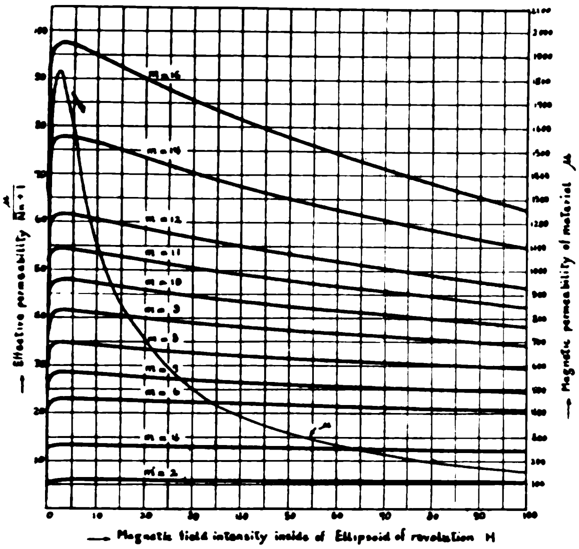

Figure 4—Relation of Effective Permeability of Various Ellipsoids of Revolution to Field Intensities Inside of the Ellipsoids

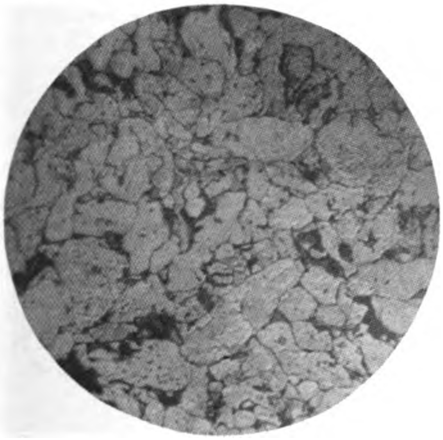

Figure 5*A*—Photomicrograph (Enlarged 100 Times) of Surface of One of the Powdered Cores

The value of $\bar{N}$ for a powdered iron core cannot be calculated mathematically so that the inductance of the core is measured experimentally and, by substituting the value of μ of electrolytic iron in formula (9) with other values of physical dimensions and constants, $\bar{N}$ is calculated backwards, so to say. The method employed for measuring inductance of a coil having a core of this kind will be described later.

In the case of a core of powdered iron hardened with wax, instead of being compressed, the mean $\bar{N}$ for the particles can be approximated. The particles in this case may be considered as spheres, in the direction of magnetization. Then mean $\bar{N}$ of the particles can be assumed to be $4\pi/3$ and, therefore, the effective permeability, of the core will be

$$\frac{\mu}{\bar{N}\kappa + 1} = \frac{4\pi\kappa + 1}{\frac{4\pi\kappa}{3}} \doteqdot 3.$$

This indicates the fact that such a core has an effective permeability of approximately three times that of an air core. This furnishes the reason why the powdered iron core in its early stage of development, had an effective permeability of very small value and, therefore, was, not suited for a core material in practice.

Again,

$$\frac{\mu}{\bar{N}\kappa + 1} = \frac{4\pi\kappa + 1}{\bar{N}\kappa + 1}.$$

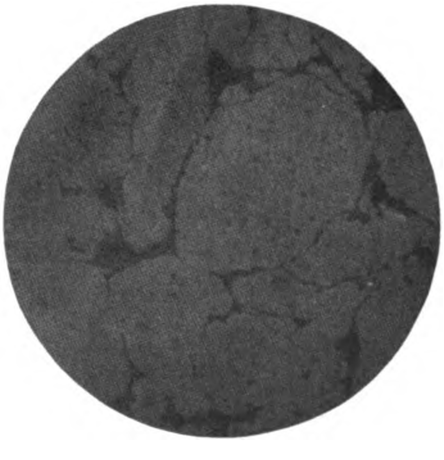

Figure 5*B*—Photomicrograph of the Surface Shown in Figure 5*A* but Enlarged 400 Times Instead of 100

If the value $\bar{N}\kappa$ in this expression were very large as compared with 1, the same expression would be reduced to

$$\frac{\mu}{\bar{N}\kappa + 1} \doteqdot \frac{4\pi\kappa}{\bar{N}\kappa} = \frac{4\pi}{\bar{N}}$$

and become a constant. If effective permeability of a core is constant, the inductance of the coil with such a core is constant and its magnetic stability will be perfect. But in such a case, effective permeability would usually be very small just as was shown in the case of the powdered iron core which is not formed by compression but hardened with wax only. When $\bar{N}$ is further removed from 4π, $\mu/\bar{N}\kappa + 1$ varies with the change in μ and κ, and a larger effective permeability is obtainable but the stability diminishes accordingly. The limiting case $\bar{N}=0$ is solely controlled by μ and the stability vanishes. This is the case where small iron wire was used for core, and points out the fact that the inductance of a loading coil of this type would invariably change with the current density variation.

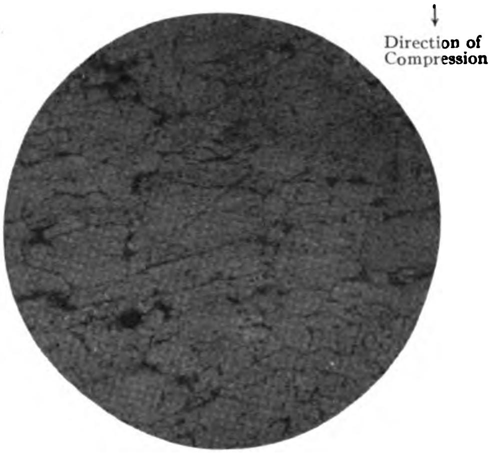

Figure 6A—Photomicrograph (Enlarged 100 Times) of Cross Section of Piece Shown in Figure 5A

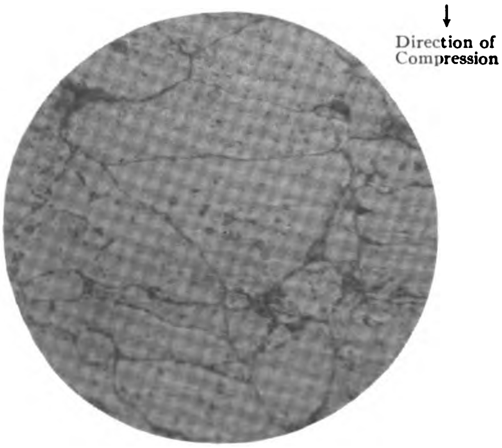

Figure 6B—Photomicrograph of the Cross Section Shown in Figure 6A but Enlarged 400 Times Instead of 100

Figure 4 shows the variation of the effective permeability of various ellipsoids of revolution according to the various field intensities which would exist inside of the ellipsoids. These ellipsoids are assumed to be of iron which has the same permeability as shown in the figure. Figure 5A is a photomicrograph (enlarged 100 times) of the surface of one of the powdered cores and 5B is the same as 5A except that the enlargement is 400 times instead of 100. Figure 6A is another photomicrograph (enlarged 100 times) of its cross section, cut perpendicular to the magnetic flux path—pressure was applied from both sides (above and below) of the core. Figure 6B is the same as 6A except for the size being enlarged 400 times instead of 100. While the photograph of the surface shows irregularity of particles in shape but without trend for any particular shape or form, cross sectional views show distinctly the deformation of grains in the direction of compression. From these photographs it can easily be seen that these particles are compressed nearly to a disc form and the magnetizing force is in the direction parallel to the flat surfaces of these discs. The demagnetizing factor $\bar{N}$ for the circular disc, magnetized in the direction perpendicular to its axis, can be very roughly estimated to have a like value of $\bar{N}$ as an ellipsoid of revolution having the same value of m as would obtain in the case of a circular disc which is folded in half and rolled up with the folded edge in the centre.

Judging from the fact that effective permeabilities for the three standards of grade A, B and C are 55, 35 and 25, respectively, values of the ratio m for the corresponding ellipsoids of revolution and these of $\bar{N}$ and $4\pi/\bar{N}$ can be roughly estimated. The results are as follows:

Grade	*A*	*B*	*C*
m	11	8	6
$\bar{N}$	0.222	0.357	0.538
$4\pi/\bar{N}$	56.6	35.2	23.4

If we use our suppositional values of $\bar{N}$ as obtained above, and substitute in $\mu/\bar{N}\kappa + 1$ with various values of μ and κ, it is clearly seen that permeability is greatest and the stability least in A and permeability least with greatest stability in C. In Figure 6, the particles do not seem flattened out enough to justify the value, $m > 6$. Perhaps it is due to the fact that while the photograph shows the cross sectional view of the particles compressed into the disc form the majority was not cut at the centres of the discs by the surface taken in the picture so that there is not much difference between thickness and length.

Since field intensity H within a particle is,

$$H = \frac{H_0}{\bar{N}_K + 1}$$

it is never equal to the magnetizing force

$$H_0 = \frac{4\pi N i \sqrt{2}}{l \times 10}$$

unless $\bar{N}$ becomes zero; otherwise, H is usually smaller than H_0. Magnetic field intensity H' in the gaps is (due to the law of continuity of magnetic lines of induction or flux) equal to the flux density B which in turn is equal to B as expressed in formula (5). Therefore,

$$H' = \frac{\mu}{\bar{N}_K + 1} \qquad (10)$$

The greatest value of $\bar{N}$ is 4π, in which case and only then, H' becomes equal to H. However, $\bar{N}$ is usually smaller than 4π; therefore, $\mu/\bar{N}_K + 1$ is larger than 1. This proves that the intensity in the gaps of a powdered iron core is greater than the magnetizing force H_0.

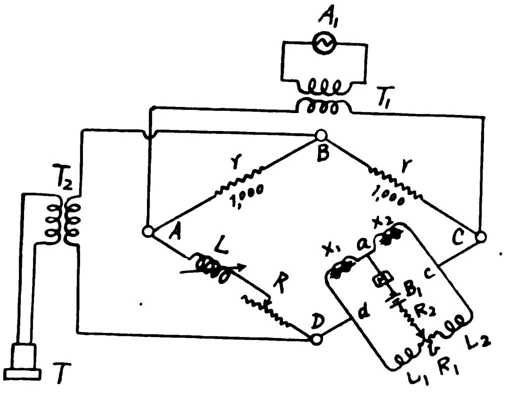

Figure 7—Method of Measuring the Inductance of a Loading Coil with DC Superposed over AC

One method of measuring the inductance of a loading coil with d.c. superposed over a.c. is done with a bridge such as the one shown in Figure 7. In this figure, A–B–C–D constitute the main and the first bridge, rr are resistances of 1,000 ohms, each forming AB and BC arms. The arm AD is composed of an inductometer L and a non-inductive resistance R; the arm CD has another bridge, called the second bridge, $abcd$. This second bridge is composed of X_1, X_2, (which are two coils with the same core under investigation and it may be seen from the diagram that these coils are connected in series with the bridge 1), L_1, L_2, (which represent air core inductance coils, whose inductance and effective resistance are balanced to each other), a non-inductive resistance R_1, battery B_1, with a rheostat R_2 and an ammeter M to measure the current flowing through ab. If a perfect balance of the second bridge is obtained, there will be

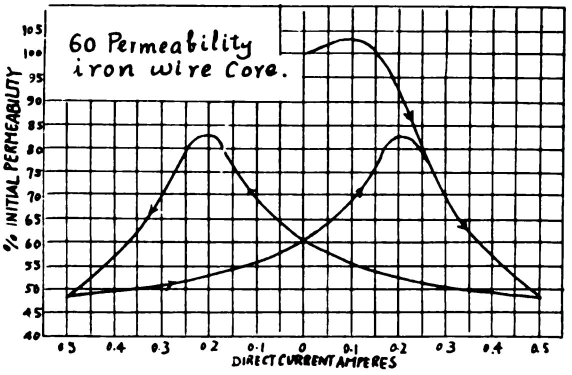

Figure 8—Variation of a Loading Coil with a 4-Mil Hard Drawn Iron Wire Core

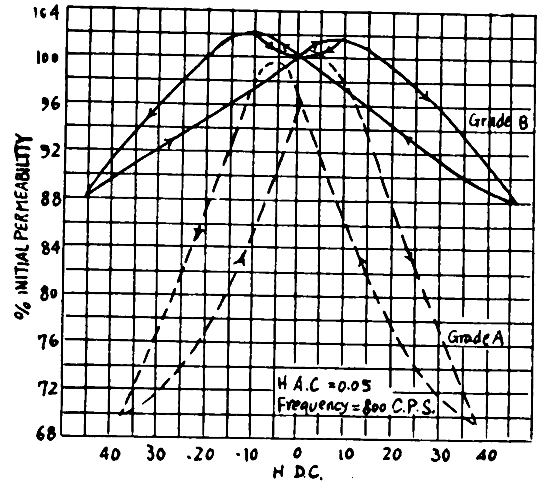

Figure 9—Variation of Loading Coils with Grade A and B Cores. DC Superposed over AC

no potential difference between points *cd*. T_1, T_2 are transformers, the former for the power source and the latter for the telephone receiver T. Both are well shielded. A is the power source of suitable frequency.

The measurement is made as follows:

(1) Balance the first bridge without d.c. in the second bridge.

(2) Superpose suitable d.c. in the second bridge.

(3) Take note of the first adjustment of L and R on the AD arm of the first bridge and then readjust them for balance. If the difference of these two adjustments be denoted by $\Delta L'$ and $\Delta R'$, the relationship between these quantities and ΔL and ΔR, denoting the changes in inductance and resistance of the two coils, X_1, X_2, due to superposition of d.c., can be given by the following formulas:

$$\Delta R = \frac{\Delta R'}{2} \times \frac{(L_1 + L_2 + X_1 + X_2)^2}{(L_1 + L_2)^2},$$

$$\Delta L = \frac{\Delta L'}{2} \times \frac{(L_1 + L_2 + X_1 + X_2)^2}{(L_1 + L_2)^2}.$$

From these equations, computations may be made to obtain the curves, showing the percentage of variation in inductance (see Figures 8 and 9).

Figure 8 shows the inductance variation of a loading coil with a 4-mil hard drawn iron wire core. This type of core is commonly called 60 permeability core and is the best among its class. Yet, as the curve indicates, from the standpoint either of residual magnetism or stability, it is inferior, by far, to a powdered iron core. Figure 9 shows the variation characteristics of the Grade A and B. The improvement is very clear at a glance.

Simultaneous Broadcasting in Czecho-Slovakia

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Introduction

SIMULTANEOUS Broadcasting refers to the process of radiating a programme, originating at any one place, simultaneously from a number of transmitting stations. The use of wireless links for this purpose has certain advantages in special cases, as for instance where it is required to bridge a great distance over the sea, but for communication over land, the use of wire circuits is more usual.

When these lines contain even short lengths of cable in their make-up, it is necessary to compensate for the unequal attenuation of different frequencies by means of networks which build up the total attenuation at each frequency to the same value. These networks are known as equalisers. It is not usually necessary to correct for the distortion introduced by open wire lines until very long lines are encountered.

To provide the correct energy levels in the lines it is essential that distortionless valve amplifiers capable of delivering adequate volume to the line terminals be installed.

Figure 1—Photograph of Prague, Showing the Castle of the Ancient Kings of Bohemia with the Cathedral in Background

Flexible switching arrangements must be supplied to enable any combination of stations to be connected quickly into the circuit, and to provide for the checking of the fidelity of reproduction and the correctness of the volume level at any point in the resulting circuit network.

The system described in this paper is a typical example of the arrangements necessary in practice to meet these requirements.

Interconnecting System

The controlling interest of the Czecho-Slovakian Broadcasting Company is held by the Ministry of Posts and Telegraphs. There are three stations located respectively at Prague, Brno and Bratislava. In addition, a 2 KW broadcaster manufactured by Standard Telephones and Cables, Ltd., London, is in process of installation at Kosice.

In the Prague station, which was described in a previous issue of "Electrical Communication,"[1] the transmitter supplies 5 KW and in the Brno Station 2.4 KW of unmodulated energy to the antenna. The station at Bratislava is an 0.5 KW outfit.

A system has been installed recently for the interconnection of the three completed stations by land lines and it is expected that Kosice will be included in the near future. Arrangements are provided by means of which the programme from any one of the studios or from a local theatre or music hall in any one of the towns may be radiated from either or both of the other stations simultaneously. Connection between Prague-Brno, and Prague-Bratislava is effected by means of circuits of which the make-up is chiefly open wire. There is no direct connection between Brno and Bratislava.

Line Connections

As an example of the type of circuit employed, the make-up of pair No. 2524 between Brno and Prague is given:

Type of Line	Length in Km.	800 Cycle Attenuation per Km. (βl/Km.)	800 Cycle Attenuation (βl)	800 Cycle Attenuation (TU)
3 mm. O.W.	161	0.0043	0.965	6.05
4 mm. O.W.	67	0.0026	0.174	1.51
5 mm. O.W.	0.45	0.0017	0.008	.07
2 mm. Krarup Cable	7.7	0.0285	0.220	1.91
Total			1.097	9.54

The measured value of attenuation at 800 cycles was 9.8 TU.

All lines are equalised in the 30–5000 cycle range by standard Western Electric 1-A Equalisers. In Figure 2 is shown the mean observed attenuation characteristics of line No. 2524, both before and after equalisation. Even with reflections present, it is evident that the departures from uniform attenuation of the final characteristic are small, it having been found possible in every case to equalise within the limits of ± 1 TU.

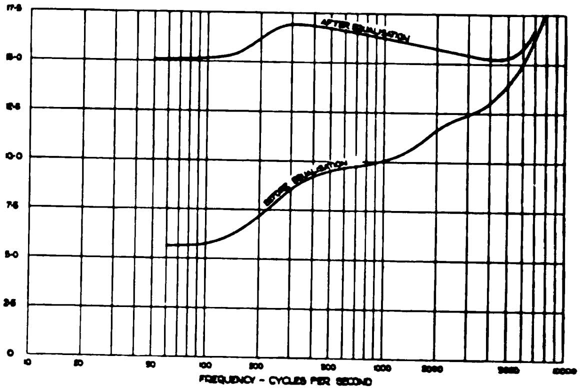

Figure 2—Attenuation of Pair No. 2524 of the Telephone Line between Brno and Prague, before and after Equalisation

Figure 3 illustrates the characteristics of a line between the National Theatre in Prague and the Control Room in Prague before and after equalisation. A view of the National Theatre is shown in Figure 4.

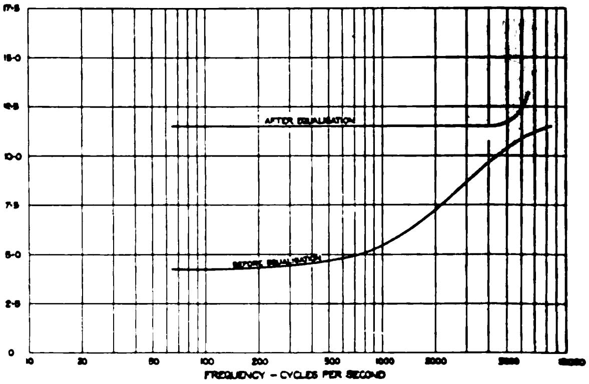

Figure 3—Attenuation of Line between National Theatre (Prague) and Studio (Prague), before and after Equalisation

It will be seen that in the present state of development of the art, the land line system introduces no detectable distortion into the transmission, and except for differences that may exist between the stations, a programme originating at any one station may be radiated with as great fidelity from any other station as from the local station.

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[1] "The Prague Radio Broadcasting Station," E. M Deloraine, ELECTRICAL COMMUNICATION, Vol. 5, No. 3, January, 1927.

In Figure 5 is shown a circuit of the type of equaliser used. This consists merely of a shunt impedance made up of a three dial variable resistance in series with a resonant rejector circuit having two alternative resonances, one for equalising to 3,000 cycles and one for equalising to 5,000 cycles. The variable resistance is adjusted to provide for different lengths of line. The values of the effective resistances of the two alternative inductances, are so chosen that the equaliser is capable of exactly neutralising the distortion in No. 19 gauge cable when an appropriate value of series resistance is inserted. Reference to Figure 3 will be of interest in connection with this statement. It should be mentioned, however, that the accuracy of measurement was not greater than ± 0.25 TU. In the system in Czecho-Slovakia all circuits have been equalised to 5,000 cycles so that the 3,000 cycle setting of the equaliser is never used. In order to economise in amplifiers, equalisation was not carried out to a frequency higher than 5,000 cycles. This is justifiable since the higher frequencies are not reproduced by existing receiving apparatus. At a later date it will be a simple matter to equalise the lines to a higher value of frequency and to increase the number of amplifiers accordingly.

Figure 4—National Theatre, Prague

Equalisers for the interurban lines, Prague-Brno, Prague-Bratislava and Prague-Pilsen are situated in the central control room of the system at Prague. Since there is but one type of equaliser, which is capable of being adjusted to fit the characteristic of any line, it is only necessary to have a limited number of equalisers in the central station, the equalisers being set to fit any line with which they are connected. Actually, four equalisers are installed at Prague; this provides for the case of a programme in a theatre in

Prague being simultaneously broadcasted from Prague, Brno and Bratislava. One equaliser is then inserted in each of the following lines: Theatre—Control Room (Prague); Control Room—Prague Transmitting Station; Control Room—Brno; Control Room—Bratislava.

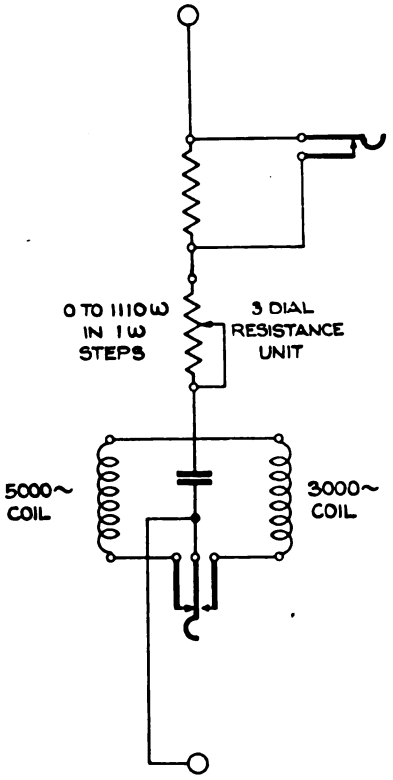

Figure 5—Circuit of Standard No. 1-A Equaliser

To illustrate the simplicity of the use of these equalisers a list of the resistance settings is given below for four of the lines measured.

	Resistance Ohms
Control Room in Prague—Brno	160
" " " Prague—Bratislava	060
" " " Prague—National Theatre in Prague	200
" " " Prague—Smetana Hall in Prague	400

After these values have been established by measurement, an unskilled attendant can equalise any line in a few seconds.

Two line impedances have been standardised for the case of a radial system such as the present one; 200 ohms at the central control station where are situated all the equalisers, and 500 ohms at the theatres and provincial stations. In the case where an equaliser is situated at a provincial station for the purpose of equalising a local theatre line, an impedance of 200 ohms must be used.

The 500 ohm value was chosen as a compromise covering the general case of all types of line at the end remote from the equaliser; and 200 ohm, as the average impedance of an equalised cable circuit at the end where the equaliser is situated. It should be realised that the preservation of exact impedance matching is of little importance provided the line is capable of being equalised to be flat when operating between impedances equal to those of the terminal amplifiers. In practice such extreme variations of impedance as would violate this condition do not occur. The only other reason for preserving impedance matching is the question of loading appropriately the output of vacuum tubes employed. Here again no difficulty is experienced, since all valves in the system are operated with a power output approximately of one hundredth of their overload power.

For the simple measurements necessary to determine the equaliser settings referred to in the preceding paragraphs, apparatus is connected at each end of the line as shown in Figure 6, where *O* is a valve oscillator preferably covering a range of 30 to 5,000 cycles per second.

V_1 is any convenient form of voltmeter, and may be a thermocouple or a valve voltmeter. The two 250 ohm resistances afford a balanced simulation of the 500 ohms impedance which will be connected to the line.

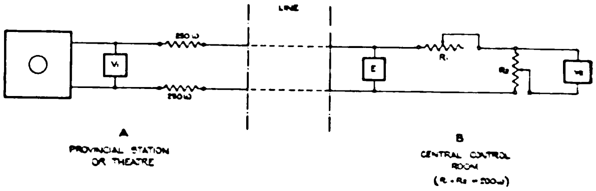

Figure 6—Arrangements for Line Measurements to Determine Equaliser Settings

E is the equaliser.

R_1 and R_2 effectively constitute a potentiometer, R_1 being decreased when R_2 is increased, and vice versa, so that the sum ($R_1 + R_2$) is equal to a constant, i.e., 200 ohms, the impedance which will close the line at the end in question.

V_2 is a high impedance distortionless voltmeter of sufficient sensitivity. It is convenient to employ a detector valve preceded by a resistance coupled amplifying stage. Standard 4102-D valves having a voltage amplification of 30 are used. The variation in sensitivity is only 6 percent from 100 cycles to 10,000 cycles and so can be neglected.

To equalise to 5,000 cycles, that frequency is supplied at A, and R_1 and R_2 are adjusted to give a suitable deflection on the voltmeter; this deflection is noted. Since the inductance and capacity elements of the shunt are in resonance, at the above frequency, the variable resistance in the equaliser makes little difference to the deflection, but it is usual to guess the final value and to set the equaliser resistance at this value. The lowest frequency to which it is required to equalise is then supplied at A, and with the same deflection on V_1 as for 5,000 cycles, the resistance in the equaliser is adjusted until the same deflection as was obtained at 5,000 cycles on V_2 is again obtained. This value of resistance is then the required value. In every case, however, it is advisable to make a check test at frequency intervals not greater than an octave, and in this case it always was done. During the check test the resistance in the equaliser is kept constant, and R_1 and R_2 are varied to keep the deflection on V_2 constant; the values of R_2 then give directly relative values of voltage ratio between the input and output of the line.

Volume Level of Speech and Music

In every case during transmission the volume at the input to an interurban line is adjusted to an energy level about 2 TU. higher than zero level, the latter being taken as 5.9 milliwatts. Standard volume indicators are provided at the control room in Prague, and also at the local stations, by means of which the power level delivered to any line may be measured.

With this volume it is found that the received energy is sufficiently high to overcome interference, while the input energy is not sufficiently high to cause trouble in neighbouring circuits.

Circuit Arrangements

In the control room at Prague is a 100-line exchange fitted with single two point break jacks and a certain number of ringing indicators. The ringing indicators are bridged across the interurban lines and the theatre control lines. The interurban lines are brought out to two jacks in parallel but the indicators are so wired that they are disconnected when a plug is put into either jack. Only single lines are provided between the towns. These lines have, therefore, to serve both for music lines and control lines. The installation of a superimposed telegraph circuit for control during broadcasting is being contemplated. In Figure 7 is indicated the general arrangement of the switchboard in Prague. Equalisers and volume indicators are brought out to jacks so that they can be connected with any line as required.

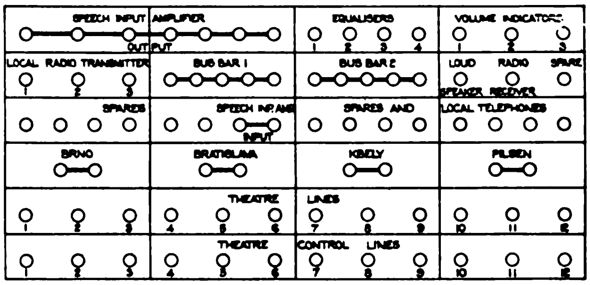

Figure 7—General Arrangement of Simultaneous Broadcasting Switchboard at Prague

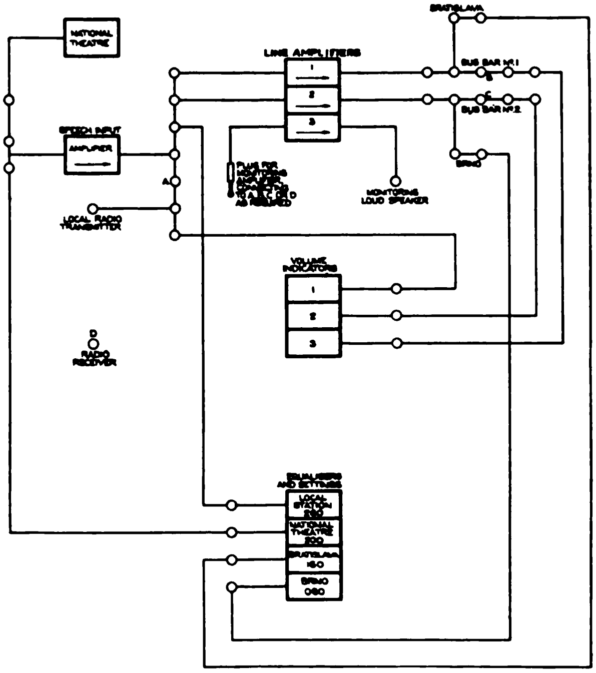

Figure 8—Control Room Arrangements of Simultaneous Broadcasting System

Distribution of programmes to the interurban lines is effected by means of Western Electric Amplifiers inserted in the special cord circuits of the exchange. During transmissions the inputs of these amplifiers are connected in parallel to the output of the speech input amplifier which is connected with the local transmitter in the standard manner. For the purpose of maintaining flat transmission characteristics, one 10,000 ohm resistance is inserted in each leg of the input of each line amplifier. As the amplifiers have a high output impedance, standard impedance matching transformers are inserted between the output of each amplifier and its line.

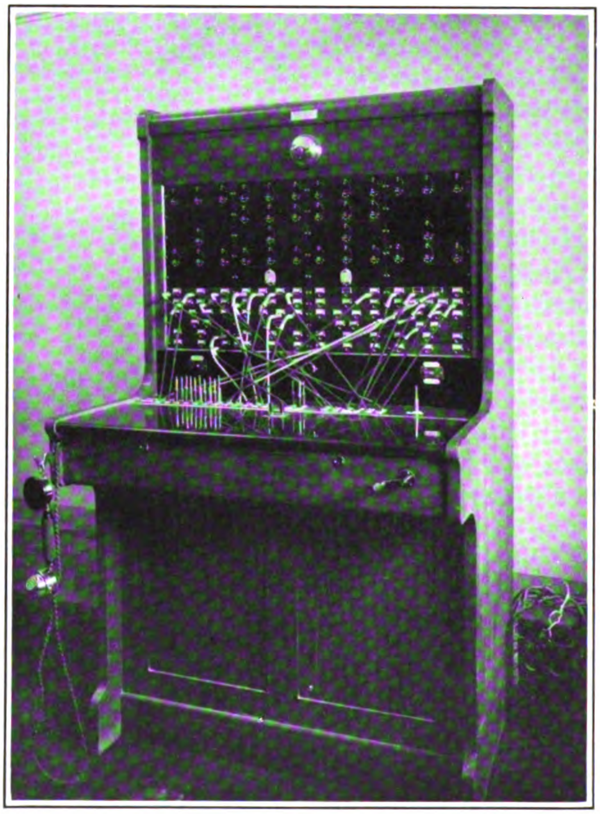

Figure 9—Simultaneous Broadcasting Switchboard at Prague

In Figure 8 are shown the circuit arrangements for the simultaneous broadcasting of a programme, originating in a theatre in Prague, from the three stations, Prague, Brno and Bratislava.

Arrangements are provided so that either of the impedance matching transformers associated with the line amplifiers may be associated with the amplifier normally used with the loud speaker for monitoring purposes. The arrangement is in fact symmetrical, so that the loud speaker amplifier forms a spare for the line amplifiers.

Figure 9 shows a general view of the switchboard in Prague. It might be mentioned that the illustration is not altogether up to date, inasmuch as certain changes in the equipment were made after the photograph from which the figure was reproduced was taken. The switchboards at Brno and Bratislava are of similar construction, but are arranged for fifty lines.

Figure 10—Philharmonic Concert Hall, Prague

Summary

The outstanding features in the Czecho-Slovakian system are simplicity, reliability and flexibility of operation. The system is constructed so that it is capable of unlimited extension in a manner such that these qualities may always be retained. The only improvement of importance to be incorporated in the system is the extension of the frequency range to 8,000 cycles, a change which will be introduced at an opportune time.

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Hans Christian Oersted at the Age of 26—From an Engraving by Chrétien, Paris, 1803

ODE BY HANS ANDERSEN

Til H. C. Oersted	To H. C. Oersted
Da Tanke-Lynet udsprang fra Din Pande,	When to thy mind there flashed the lightning thought,
En stoerre Seekraft Videnskaben fik,	The realm of Science, wondrous in the blaze,
En umaalt Skat Du gav til Verdens Lande,	Revealed such treasures in the Truth you taught,
Og gjennem alt det Skjoenne i det Sande,	That men before its Beauty bowed, and sought
Til Gud Du foerer os med aabent Blik.	A path to its Creator, by your ways.

R. A.

Pioneers of Electrical Communication

Hans Christian Oersted —VI

By ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

IN the history of electrical science, the first twenty years of the nineteenth century constitute the period of transition from static to current phenomena. Following upon the work of Galvani and Volta, discoveries throughout those two decades manifested themselves in all the advanced countries of Europe. In Denmark, however, at the end of that time, what had been the dream-phantasy of electrical communication suddenly took shape, inspired hope, gave confidence, and urged mankind to move towards reality; for in 1820, at Copenhagen, the secret now known as electromagnetism was wrested from nature by Hans Christian Oersted.

He was born in 1777 at Rudkjöbing, a small town on the island of Langeland, where his father was an impecunious apothecary. In 1778 a second son, Anders, completed the family for the time being, and when, in due course, the problem of education for the two boys presented itself, there were difficulties—schools in Rudkjöbing were scarce, teaching was crude, and the Danish language did not suffice for prospective needs and aspirations. The apothecary proved himself a man of resource. He enlisted the services of his friend Christian Oldenborg, a Teutonic barber and wig-maker of slender means, to teach the lads elementary German. The aid of the barber's wife was sought also to help them to learn to read and write. Arithmetic was at first an embarrassment, for the barber's knowledge in that direction was limited to addition and subtraction. Happily, a friendly schoolboy disposed of this trouble by imparting the rudiments of multiplication and division. From the baker they learnt a little drawing; from the burgomaster, a smattering of French; and from the local surveyor, some mathematics. Moreover, when Hans was twelve years of age, he assisted his father in the apothecary business, and thus acquired the beginnings of chemistry. A few years later, he gained increased access to books and developed an inclination towards literature. Notwithstanding privations, the two boys studied hard; their intelligence was above the average, and their parents endeavoured by every available means to assist them to materialise their aspirations. Hans and Anders were so successful that in 1794 they passed the students' examination and six months afterwards entered Copenhagen University. There they derived a little support from State funds, and made up the remainder by teaching. At that time, as physics and chemistry were not accepted by the University for a diploma, Hans directed his attention to pharmacy. In 1797 he passed in that subject with honours. He gave attention also to physics and astronomy. As his brother's ambition was to be a jurist, it was possible for them to study together certain subjects appertaining to both of their respective professions. They shared one lodging and, for a time, they shared one amusement—their scientific work. They shared expenses. They also shared one friend—the poet Oehlenschläger. The poet had one sister. She married Anders.

At the age of 20, H. C. Oersted showed definitely his bent towards literature and philosophy. So far did he improve his acquaintance with these subjects, that in 1797 he secured the University prize, a gold medal, for an essay "On the Limits of Poetry and Prose," and he won, in 1799, the prize for metaphysics.

His learning was becoming wide as well as deep. In his writings, early and late, may be discerned the influence of the German thinkers, Von Schelling (1775–1854, of Jena) and Kant (1724-1804, of Königsberg), whereby he was led to dwell upon the philosophy of nature, to treat facts in poetical fashion, and to perceive, in the study of physics, something of romance and of estheticism. Thus was he taught to distinguish between the individual and the material system that surrounds the individual, to separate matters of knowledge from matters of fact, sense from understanding and mind from things, to seek to combine and to marshal in thought the scattered elements of experience, and generally to approach towards transcendental theology. On obtaining his degree as Doctor, this influence was recognised in his thesis, the title of which was "The Architectonicks of Natural Metaphysics," and it was destined to play a significant part in his subsequent career. To the present age, such philosophy appears fantastic, but whatever may have been its merits or defects, the attempt to master it gave activity and scope to his imagination and induced him to perceive or to dream of identity between all manifestations of energy, such as light, heat, chemical action, electricity and magnetism.

The year 1800, memorable for the introduction of Volta's pile, discovered Oersted again doing service in an apothecary's shop, but not at Rodkjöbing. This establishment, which to-day still flourishes in Copenhagen, bears the name by which Oersted knew it—the Loeveapotheket (Lion Apothecaries). It was owned in 1800 by Professor Manthey, who happened to require the services of a pharmacist to whom he might entrust the business while he himself made a tour in Europe. Oersted, alive to the discoveries that had just been made by Volta, welcomed the opportunity this gave him for research. His first success related to the selection of solutions to produce the best results for the purposes of "galvanic electricity." He was impressed by the surprising results he was able to obtain by careful adjustment of the proportion of acid to water in the galvanic generator. He was also at work upon the classification of the earths and alkalis. In 1800, moreover, he took the Chair vacated by Manthey as Professor of Surgery. Reward for this labour came in the following year, when he gained at the University a money prize—the *stipendium cappelianum*—which supplied the means for him to travel for a few years at the expense of the State.

As soon as Manthey returned to Copenhagen, Oersted departed, in 1801, for Germany and France, filled with a desire to discuss pharmacy, metaphysics, and chemistry with men of light and leading. He found in Germany a realm of theory, in Paris a paradise of experimental philosophy. The tour enlarged his sphere of activity, brought him into touch with his peers, taught him the measure of himself, and indicated the lines of progress. The friendships that were to prove of greatest immediate significance, however, were that of Winterl and of Johann Wilhelm Ritter (1776–1810) who at that time was living at Weimar.

The quality of Oersted's literary powers was at this time illustrated by an episode that reflected credit alike upon his ability and upon his generosity. In the years 1802–1803 he was in Paris, and Ritter had just discovered the Ladungsaüle (secondary cell), consisting of a stack of plates of a single metal separated by discs of cloth or cardboard damped with an inert liquid, and charged by a voltaic pile. With it, Ritter produced sparks, decomposed water and salt solutions, collected oxygen, hydrogen and bases, and gave other remarkable evidences of its powers. Unfortunately, he could not speak, what he called, the "eigenthümlich-dunklen Sprache" of the French, but he desired to compete for the annual prize of the French Institut in natural science. Accordingly, he prevailed upon Oersted to prepare a translation from German into French. This Oersted did so well that Ritter declared he could himself understand the translation better than his own original German.

On his homeward way from Paris, in 1803, Oersted visited Brussels, Leiden, Haarlem and Amsterdam. At about that time, the University of Copenhagen was partly destroyed by fire, and the physical laboratory was burnt. The city fortunately contained a separate collection of physical apparatus, but it was held in private hands and Oersted could not at first secure free access to it. By judicious borrowing, however, he ultimately assembled what he required for a series of public lectures on electricity, magnetism, heat, light and combustion. His mind in these years was centred chiefly upon electro-chemistry, but he was still concerned with the identification of general laws, exemplified in all branches of natural philosophy. He was a keen observer, and gradually he developed into an enthusiastic experimenter. His experiments on tone-figures, carried out in 1806, proved to be of sufficient importance to lead to his appointment as extraordinary Professor of Physics at the University of Copenhagen. This increased the facilities at his disposal for further investigations. He became a teacher also at the Military School, and gave lectures to the general staff. In 1809 he produced a textbook of mechanical physics, which was republished in an enlarged edition in 1844.

In 1812–1813, Oersted made another tour in France and Germany. He remained a long time in Berlin, and published there, in German, his researches upon the identity of electric and chemical forces, which had already appeared in French in Paris. Upon his return to Copenhagen in 1814, he married, on May 17th, Inger Birgitte Ballum who was born on March 28, 1789, and who died on November 3, 1875. She was a daughter of N. R. Ballum, a pastor of Kjelby on the small island of Moer. At about the time of his marriage, he associated himself with a movement to introduce into chemical terminology the Gothic and German languages to displace the Greek and the French. In addition, he sought to raise science to the status of religious culture. He usually worked with his classes, in lectures and otherwise, for five hours every day, and it was his custom to give each month a special lecture to explain new advances in science.

Then came the year 1820, the year of his great discovery, the happiest year of his life. By what has been described as one of those lucky throws that come not twice in a thousand years to mortals, he found that an electric current can deflect a compass-needle. He reasoned that just as an electric current can produce heat and light, so it might exert magnetic influence. He had for some years possessed the germ of this idea. He convinced himself that every voltaic circuit has a magnetic field, and that the direction of movement of a magnetic needle placed near such a circuit is determined by that field. An account of his investigations, in Latin, was distributed by him to Societies and Academies in all the capitals of Europe. Praise and honours came in upon him from all sides. From the Royal Society of London he received the Copley Medal, and from the Institut of France a prize of 3000 francs.

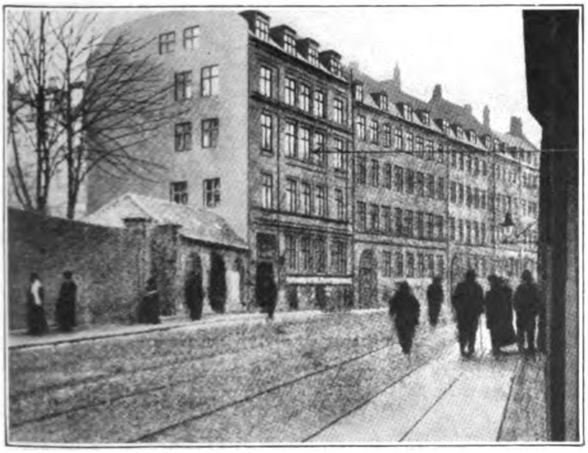


Figure 1—Oersted's House in Noerregade, Copenhagen. The original photograph was taken in 1907, shortly before the building was demolished to make way for Telephone House. The arrow indicates the room in which the first experiment on electromagnetism was performed.

Figure 2—Telephone House, Copenhagen—The Headquarters of the Copenhagen Telephone Company.

The exact date of Oersted's discovery of electromagnetism is unknown. Arago (*Oeuvres*. Vol. 2, p. 50) assigns it to 1819, but it may have been in the early Spring of 1820. The announcement was dated from Copenhagen, July 21, 1820, and time must have been necessary to prepare that account. The place where the discovery was made has been carefully ascertained.

In 1819 Oersted had moved to a house, Noerregade 34 (Figure 1), belonging to the cabinet maker, Pingel. There for five years he remained. The house, which has since been demolished, was located at what is now the southern end of Telephone House (Figure 2). It resembled a previous house there that, in common with all others in the street, was destroyed in the bombardment of 1807. Oersted rented, on account of the University, seven rooms on the third floor front and four rooms at the back for £77 a year. His private dwelling was

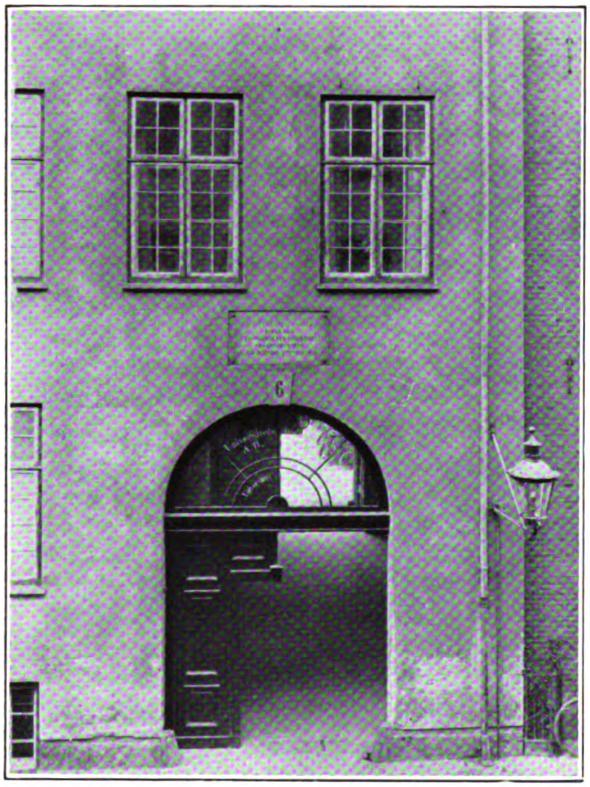


Figure 3—Entrance to Studienstraede 6, an Annex of Copenhagen University. The memorial plate above the doorway records that H. C. Oersted lived there as a Professor from October, 1824, until his death on March 9, 1851.

on the second floor. The two rooms facing Noerregade formed the lecture-room, the scene of the discovery; the others were preparation rooms. It has been possible to locate approximately the point in space, in Telephone House, where the original experiment was performed.

In 1824, Oersted departed from Noerregade, 34, and occupied a Professor's house (Figure 3), belonging to the University, at Studienstraede 6. In 1829, he founded the Polytechnic School and allowed some of the rooms of his own house to be used by that institution. At that time there was a courtyard separating his house from a private building, afterwards requisitioned by the University (Figure 4). In 1890, for the centralisation of studies in Physico-Chemistry, Inorganic Chemistry, and certain branches of Mathematics, all the polytechnic schools were transferred to a new building in Soelvgade.

On the day of his discovery, when he had assembled the apparatus, a lecture prevented him from trying what he had in mind. At the close of the lecture, he asked his class whether they would like to observe what might happen. The class remained and witnessed the result—a deflection of the compass-needle (Figure 5), when there was an electric current in a neighbouring wire, placed in proper relation to the needle. The movement was so small that Oersted was inclined at first to attribute it to capricious disturbances. Moreover, he was perplexed because he could not account for the fact that the movement of the poles of the pivoted magnet, in a horizontal plane, was at right angles to the direction of the current in the wire. Why was not the line of action of the magnetism the same as that of the originating electric current? Later, he returned to the investigation; he now used a much larger battery—copper-zinc, sulphuric acid—and he obtained a decided deflection of the needle. His procedure was thus in accordance with the most

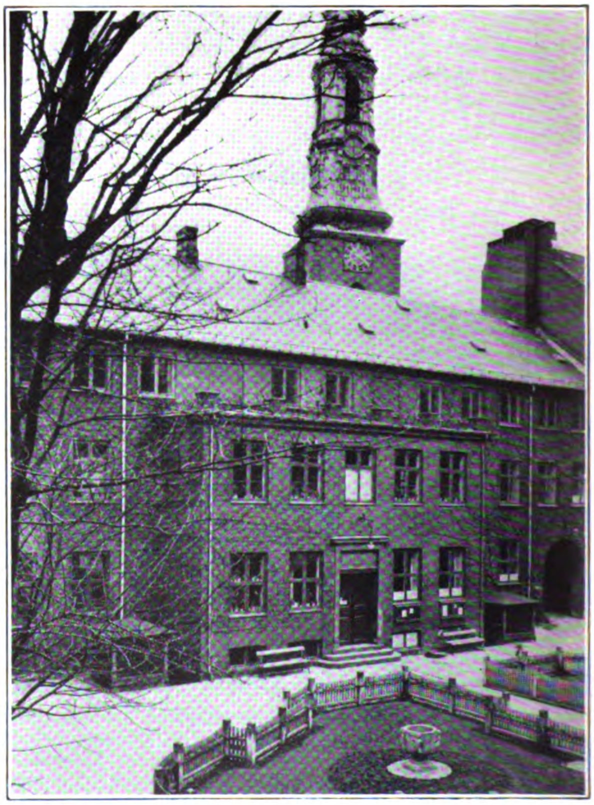


Figure 4—Royal Technical College, Founded by H. C. Oersted in 1829. Here he lectured. It is now an annex to Copenhagen University. In the background is the tower of the Church of St. Petrie. There is a legend that to this tower Oersted extended wires from his house opposite, and installed the first electromagnetic telegraph signaling device in Denmark.

cherished methods and traditions of the pioneers: to his imagination he gave scope enough to inspire him with a definite object of research, by experiment he sought in the direction of that object for new facts and, lastly, when a clue appeared, he extended the research in each direction, towards weakness and towards strength, far beyond the limits required for a class demonstration of the phenomena.

In other investigations he studied especially the constitution and properties of water, and he developed for this research a new instrument (Figure 6) for measuring the compression of liquids. Later he examined the pressure-volume law for air, and other substances, and he carried the pressure to the limits of the apparatus then existing. Further, he investigated the derivation of aluminium from clay, and a new method of preparing oxides of chlorine.

A third State-aided tour, in 1822–1823, took him to England, France and Germany. On that occasion he had an opportunity to observe especially the progress of investigations with regard to light, and he replenished the laboratory at Copenhagen with a number of instruments. On his homeward journey he established the "Society for the Distribution of Teaching Natural Science." In 1828 he visited Norway and Berlin where he addressed the physicists; and in 1830 he made a similar visit to Hamburg.

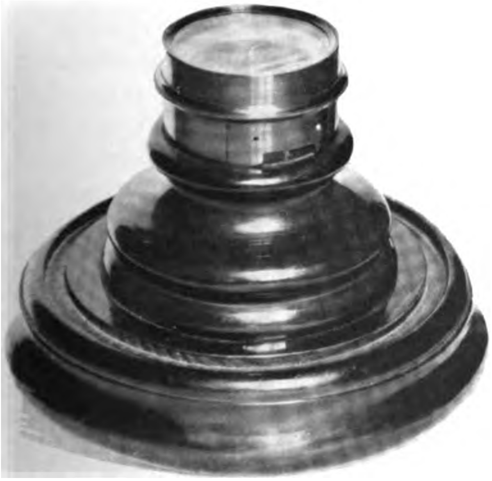


Figure 5—The Compass Used in H. C. Oersted's Original Experiment on Electromagnetism. The wooden support was added later. The instrument is now in the Museum of the Physical Laboratory of Copenhagen Polytechnic Institute.

He next appears in 1834, discussing questions of physics at Göttingen with Gauss, whom he had met at Altona in 1827. From him he heard of the latest observations in magnetism, and of the new methods of measurement that Gauss had introduced. This concerned Oersted, for he had in mind the establishment of a magnetic observatory at Copenhagen. A few years later, he again went to Scandinavia, where he discoursed upon subjects in a plane beyond the conventional circle of natural philosophy—he lectured upon the relation of physics to beauty, somewhat in accordance with Leibnitz's hypothesis of harmony and unity between the laws of nature and the laws of reason.

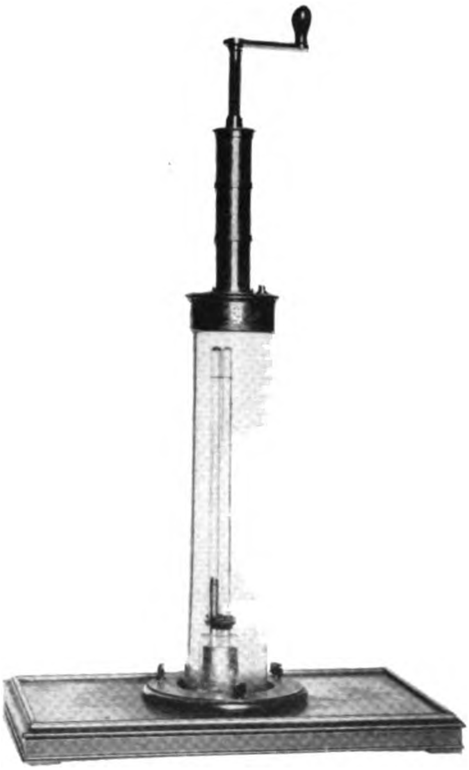


Figure 6—H. C. Oersted's Piezometer, Now in the Museum of the Physical Laboratory of Copenhagen Polytechnic Institute. The barometer tubes inverted in mercury are seen within a glass cylinder having thick walls. The whole was filled with water or other liquid, and the pressure was applied by the piston, operated by a screw rotated by the handle.

His study of Danish literature never ceased. Into political affairs he entered boldly, and he made frequent communications to newspapers and journals, pleading for freedom of the press and for the advance of generous ideas in government. At the other extreme, he went so far as to write in 1836 a great lyric-didactic poem entitled, "The Air Ship." It will suffice here to quote briefly from L. and J. B. Horner's English translation:

> "Turn, then, and look
> Upon the varied business of man's being,
> Where the inventive spirit finds fit work
> For the free hands to do. In sooth, we might
> A thousand wonders add unto the seven
> Which the past world astonished.
>
> . . . .
>
> What Nature lent
> Her feathered children of the air—to soar
> With outspread wing, free in Heaven's azure vault—
> Art has outdone; and now majestic floats
> The dweller of the earth in regions where
> The kingly eagle has not dared to soar.
> Did not the hapless fate of Icarus
> The poet warn, that such an airy flight
> Secure he cannot dare? Praised be the age
> When wonders are so rife, that one like this
> Is lost among their number manifold."

Oersted, however, was not the first to derive poetic inspiration from the advance that was being made in aeronautics. The subject had long engaged the attention and had fired the imagination of men in the front rank of natural science. Twenty years earlier, Sir George Cayley had contributed a valuable article to the *Philosophical Magazine* (Vol. 47, No. 214, February 1816) on aeronautics, and had concluded with a verse, at once stirring and prophetic, by Dr. Darwin:

> "Soon shall thine arm, unconquer'd steam afar
> Drag the slow barge or drive the rapid car;
> Or on wide waving wings expanded bear
> The flying chariot through the fields of air.
> Fair crews triumphant, leaning from above,
> Shall wave their fluttering kerchiefs as they move;
> Or warrior bands alarm the gaping crowd,
> And armies shrink beneath the shadowy cloud."

Behold Oersted now, Secretary of the Königl. Gesellschaft der Wissenschaften; Professor Ordinarius at Copenhagen; Corresponding Member of the Science Academie of the French Institut; Director of the Polytechnic School of Copenhagen, which through his personal influence with Friedrich VI he personally had called into existence; Knight of the Ehrenlegion (1837); Conferenzrat (1840); Knight of the Prussian Order *pour le mérite* in the Sciences and Arts (1842); possessor of the honorary diploma of Erlangen as Doctor of Medicine (1842), and of the Grand Cross of Dannebrog (1847). These dignities, however, did not prevent him from extending his studies, his sympathies, and his beneficent influence.

To appreciate the scope and character of the man and his achievements, it is necessary to recall the turbulent age and circumstances in which he lived. His boyhood was marked by the war of 1789, between Denmark and Sweden, by the struggle against serfdom in his country, and by a general movement towards political freedom. In the subsequent wars, Denmark—threatened by Napoleon—entered a league that brought her into conflict with England. In 1805, Napoleon overthrew Austria and Russia at Austerlitz, and formed the Confederation of the Rhine under the protection of France. This was followed in 1806 by the abdication of the Emperor Francis II, an event that marked the end of the Holy Roman Empire. The ultimate result was that when, in 1814, the Napoleonic Empire began to fall to pieces, Denmark lost possession of Norway, and suffered impoverishment and distress, followed by an interval of agitation for a free constitution—an agitation that in various phases disturbed the country to the day of Oersted's death.

To comprehend where Oersted stands in the world's history, therefore, it is essential to realise the perilous position of his country at several periods during his long life. The main trouble began in 1780, when Denmark declared the Baltic to be closed to the armed vessels of belligerent Powers. At that time England was at war with the American Colonies, and also with France and with Spain. Holland, Denmark, and the whole Baltic sought nevertheless to trade with England's enemies, in timber, tar, hemp, cordage and provisions. England accordingly used armed vessels to search merchantmen. The Dutch held that a neutral flag should exempt from seizure. England replied by attacking the Dutch. Russia assisted merchantmen bound for French ports. Sweden and Denmark formed an alliance to protect their trade. Denmark meanwhile kept in close touch with Russia and, on December 7, 1800, Bonaparte joined the Russian league and devised a plan to invade India. His first move in this direction, however, was towards the commercial exclusion of English commerce from the continent of Europe. England hit back by placing an embargo on Russian, Danish, and Swedish ships in British ports, and at the same time she fitted out a fleet for the Baltic.

Denmark supported by France, followed by placing an embargo on all British ships in her ports; she entered Hamburg and closed the Elbe to the English, she took possession of Lübeck and, aided by Prussian troops, the combined forces closed the Weser and the Ems to English vessels.

In the early Spring, England restored the balance by sending her fleet through the Sound, and by attacking Copenhagen. This fleet was under the command of Sir Hyde Parker, with Vice-Admiral Nelson as second in command. Parker did not excel, but Nelson, with his accustomed skill and zeal, accomplished the task. Parker held himself in reserve with many of his ships and, thinking that Nelson would suffer a reverse, made the signal, "Discontinue the action." It was then that the famous incident occurred in which Nelson turned his blind eye to the telescope and hoisted his own battle signal, "Engage more closely." Copenhagen collapsed; Russia also gave in to England, but France did not.

The next event that closely concerned Oersted was in 1807. Bonaparte insisted that Denmark, Sweden and Portugal should be compelled by France and Russia to enter into war against England. His object was to add the navies of Denmark, Sweden and Portugal—about forty ships of the line—to his forces. For England, it was a matter of life or death, and her immediate counter blow was to seize the Danish fleet. Admiral Gambia sailed from England on July 26, 1807, with forty-two fighting ships, and also with twenty-seven thousand troops under Lord Cathcart. Zealand was blockaded, Copenhagen was bombarded from September 2d until September 5th of that year, and the entire Danish fleet of eighteen sail of the line, ten frigates, and forty-two smaller vessels were forced to surrender.

A great misfortune fell upon H. C. Oersted in 1813 when his brother, Niels Randulph Oersted, who was an officer in the Russian army, was killed at the battle of Leipsic. The troubles of his country pursued the great philosopher to the end, for in 1848 Germany was seeking to annex part of Denmark, and the Danish army absorbed much-needed wealth. It is noteworthy that in France, in 1848, Arago was Ministre de la Guerre et de la Marine, and that Oersted, counting upon their friendship in the field of science, tried through him to influence French opinion concerning Slesvig in favour of Denmark, but without success.

It is necessary next to glance at the state of electrical knowledge as Oersted found it, and as he left it. That lightning, from a distance, could reverse the poles of a magnet, and that an electric discharge from a Leyden jar would have the same effect, was familiar to him. Benjamin Franklin, in 1749, had used these facts as an argument in proof of the identity of lightning and electricity; and "the magneticalness of lightning" had been referred to in 1756, in a history of the Royal Society. Similarly, that there was possibly an analogy between electricity and magnetism had long been a suggestion amongst physicists; for in 1767, Jan Hendrik Van Swinden, of Amsterdam, had discussed it in a prize essay and had decided that there is no definite analogy. There must be recalled also the circumstance that, in 1802, Adam Walker published "A System of Familiar Philosophy" relating to the identity of light, heat and electricity, as modifications of a single agency, and that he declared that, "we have infinite data in favour of an electromagnetic fluid."

Hence, it is not surprising that Oersted's discovery was, at first, imperfectly understood, and that there were critics who suggested that it had been anticipated. Earlier, he had himself vainly endeavoured with Ritter to trace an action between electricity and magnetism. Particulars of this investigation are to be found in the correspondence between the two physicists. To establish the priority of Oersted, it remains only to clear the issue in respect to results obtained by the Italian lawyer and mathematician Romagnosi. The case in favour of Oersted, in this instance, was established definitely by his countrymen, Absalon Larsen, K. Prytz and M. C. Harding. To elucidate the matter, it was desirable to dispose of the accounts of Romagnosi's results as given by Professor Giovanni Aldini in his *Essai*, published in 1804. At page 339 of the *Essai*, after describing certain developments in galvanism, Aldini directs attention, as follows, to an experiment which he ascribes to the Genoese chemist Giuseppe Mojon:

"Ayant placé horizontalement des aiguilles à coudres, très fines, et de la longuer de deux pouces, il en a mis les deux extrémités en communication avec les deux pôles d'un appareil à tasses de cent verres: au bout de vingt jours il a retiré les aiguilles un peu oxidées, mais en même temps magnétiques, avec une pôlarité très sensible. Cette nouvelle propriété du galvanisme a été constatée par d'autres observateurs, et dernièrement par M. Romanesi, physicien de Trente qui a reconnu que le galvanisme faisait décliner l'aiguille aimantée."

(Having placed horizontally, some very fine sewing needles, two inches in length, he put the two ends in communication with the two poles of a battery of 100 cells: at the end of twenty days, he removed the needles slightly oxidised, but at the same time magnetic, with a very perceptible polarity. This new property of galvanism has been established by other observers, and lastly by M. Romagnosi, a physicist of Trente, who has noticed that the galvanism causes the magnetised needle to decline.)

What then was the experiment carried out by Romagnosi?

The *Manuel du Galvanisme*, by Joseph Izarne, published in Paris in 1805, contains a description of the various forms of galvanic apparatus employed up to that time for researches in physics, chemistry and medicine. As Izarne was Professor of Physics at the Lycée Bonaparte and as he was associated with the learned societies concerned with galvanic research, his testimony may be accepted as representing enlightened contemporary knowledge of the subject. At page 120 he deals with magnetic effects of electrification, and he describes:

"APPAREIL POUR RECONNAITRE L'ACTION DU GALVANISME, SUR LA POLARITÉ D'UNE AIGUILLE AIMANTÉE

"*Préparation.* Disposez les tiges horisontales *a b*, *b d*, de l'appareil . . . de manière que les deux boutons se trouvent à une distance un peu moindre que la longueur des aiguilles que vous voudrez soumettre à l'expérience; et, à la place des boutons *bb*, qui sont vissés sur leur tige respective, adaptez aux tiges, ou une petite pince, ou bien un petit ajutage applati.

"*Usage.* Après avoir placé l'aiguille, de manière que ses deux extrémités soient prises dans les deux petites pinces, établissez une communication de d, avec une des extrémitiés d'un Electromoteur (Volta pile, *vide* p. 19), et de a, avec l'extrémité opposée.

"*Effets.* D'après les observations de Romagnési, physicien de Trente, l'aiguille déja aimentée, et que l'on soumet ainsi au courant galvanique, éprouve une declinaison; et, d'après celles de J. Mojon, savant chimiste de Gênes, les aiguilles non-aimentées acquièrent, par ce moyen, une sorte de polarité magnétique."

(APPARATUS TO SHOW THE EFFECT OF GALVANISM ON THE POLARITY OF A MAGNETIC NEEDLE

Preparation. Arrange the horizontal rods *ab*, *bd*, of the apparatus (Figure 7) in such a manner that the two knobs are at a distance apart a little less than the length of the needles with which it is desired to experiment; and at the knobs *bb* that are screwed to their respective rods, attach a small clip or a small flattened extension.

Manipulation. After having placed the needle in such a manner that its two ends are held in the two small clips, establish connection from *d* with one of the terminals of the Volta pile, and from *a* with the opposite terminal.

Effects. According to the observations of Romagnosi, a physicist of Trente, a needle already magnetised and subjected thus to a galvanic current will show a declination; and according to those of J. Mojon, a learned chemist of Genoa, non-magnetised needles acquire by this means a sort of magnetic polarity.)

Here, there is nothing in common with Oersted's experiment; for here the needles are fixed and in Oersted's case the compass needle is free to turn; here the current is passed through the needles and in Oersted's case it traverses a separate conductor.

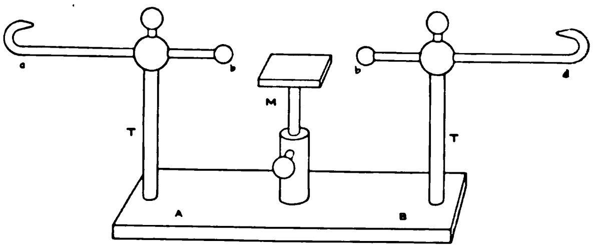


Figure 7—Apparatus as Used by Romagnosi.

The original account of Romagnosi's experiment appeared in a newspaper, the *Gazetta di Trento*, of August 3, 1802, and it leaves no doubt of the manner in which he carried out the experiment. Figure 7 illustrates the support upon which the needles were placed and held fixed by clips, and the knobs by means of which the current was passed through them. The *Gazetta* account is as follows:

"Senator Giandomenico Romagnosi, a resident of this city and known to the literary world through his other profound works, hastens to communicate to the physicists of Europe an experiment relating to the galvanic fluid as applied to magnetism.

"Having prepared the pile of Mr. Volta, composed of round discs of copper and zinc alternating with an interposed layer of flannel moistened with water impregnated with a solution of sal ammoniac, he attached to the pile a silver wire linked at various intervals like a chain. The extreme link of the chain passed through a glass tube, from the outer end of which a silver button projected, it being connected to the said chain.

"This being done, he took an ordinary magnetised needle shaped like a mariner's compass mounted at the centre of a square wooden block, and after having removed its crystal cover he placed it on top of a glass insulator in the vicinity of the said pile.

"Then he took hold of the silver chain, and seizing the same by the said glass tube, he applied its end or button to the magnetic needle, and by holding it in contact for a period of a few seconds, he caused the needle to diverge some degrees from the polar direction. After the silver chain had been removed, the needle remained stationary in the diverging direction now given it. Once more he applied the same chain making the said needle diverge still more from the polar direction, and he always obtained the result that the needle remained in the position where he had left it, in such a manner that the polarity remained entirely annihilated. In order further to verify this result, he brought as near as possible to the magnetised needle (without touching it, however), now a piece of watch spring and then other iron instruments, which previously attracted the same needle forcefully at a four times greater distance, but now when exposed to the action of galvanism they were unable to move the needle even the width of a hair.

"Now look how Mr. Romagnosi then proceeded to restore the polarity. With both hands he tightly gripped, between the thumb and the index finger, the extremity of the wooden insulated box without shaking it, and he held it thus for some seconds. Then the magnetised needle was seen to move slowly, and to recover its polarity, not all at once, but by successive pulsations in similar manner as a clock-hand serving to indicate seconds.

"This experiment was made in the middle of May, and was repeated in the presence of some spectators. On such occasions he obtained also, without difficulty, the electric attraction at a quite appreciable distance. He made use of a fine piece of thread soaked in water saturated with sal ammoniac, and attached it to a small glass rod, and then he approached the said silver chain to the thread, to within a distance of about one line, and he saw the thread fly into contact with the button of the chain and swing up, it remaining all the time attached in a manner similar to the electric experiments."

From this evidence it is manifest that Romagnosi was concerned solely with the effect of electrical discharges through the magnets themselves, and that he repeated, in effect, the experiment of Mojon, by sending a more or less continuous current through the magnets. As his magnets were fixed, he did not observe the rotary movement that was the essence of Oersted's discovery. Moreover, Romagnosi himself made no claim to such a discovery. Romagnosi observed the more or less permanent magnetising or demagnetising effect of a current through the magnets—the annihilation of polarity. Oersted did not send a current through magnets, but through a separate conductor. Consequently the novelty of Oersted's experiment may now be regarded as established beyond controversy.

The Copenhagen experiment gave to research an impulse as far-reaching as it was momentous. The account of it arrived in Paris from Switzerland, and at the meeting of the *Académie* on September 11, 1820, an academician who had just arrived from Geneva repeated it with great success. Seven days later, on September 18th, Ampère made known his grand generalisation concerning it. On September 25th, Arago described, at the Bureau des Longitudes, experiments in which a current from a voltaic pile, when conveyed through a conductor, is caused to magnetise rods of soft iron separate from the conductor. On November 16th, at a meeting of the Royal Society, Sir Humphry Davy read a paper on the magnetising influence of galvanism on bars of steel (*Philosophical Magazine*, Vol. 56, 1820, pp. 381–382). The experiments were made in the laboratory of the Royal Institution. The batteries were twelve troughs of four-inch plates, mounted with double coppers "agreeable to Dr. Wollaston's plan." In the same journal, at page 394, is an account of a further result, attributed to Oersted, and explained as follows:

> "A plate of zinc (about three inches high and four inches broad) placed in, and by an arch of small wire connected with a trough nearly fitting it, made of thin copper and containing a mixture of one part of sulphuric acid, one part of nitric acid, and 60 parts of water, forms an apparatus, which being suspended by a very small wire (only sufficiently strong to bear its weight), will, if a powerful magnet be presented to it, exhibit magnetic polarity —turning its corresponding pole to the pole of the

> magnet. The suspending wire is attached to the apparatus by a thread rising from one side of the trough to the wire, and descending to the other side of the trough; and the plate of zinc is kept from coming in contact with the copper case, by a piece of cork interposed on each side of the plate."

The *Philosophical Magazine*, Vol. 57, 1821, pp. 40–49, contains a paper by Hatchett on the electromagnetic experiments of Oersted and Ampère, in which Oersted is said to have opened up a new field to the inquiries of philosophers, for—

> "It is to him that we owe that fine observation, that a metallic wire, which communicates with the two extremities of a Voltaic electrical apparatus, acquires the very remarkable property of acting at a distance on a magnetic needle. This metallic wire has been named the conjunctive wire."

Hatchett states that it had for some time been known that conjunctive wires may become heated, redden, and burn in atmospheric air, and he emphasises the fact that—

> "For twenty-three years the electric piles of Volta had been in use, and no philosopher had yet thought of bringing a magnetic needle near one of these piles in action. This inspiration was reserved to Oersted; and it must be confessed, that chance had much less share in it than in many discoveries with which physical science has been enriched."

Oersted had long before written a memoir with the title, "An Inquiry into the Identity of Chemical and Electrical Forces," and this book was translated and published in 1807. In that inquiry, he sought for proofs that magnetic and electric forces are identical, but he found none. Hatchett remarks upon the curious circumstance that when Oersted discovered the action of the conjunctive wire upon the needle, he explained this new phenomenon by a hypothesis which supposes that the negative electricity acts only on the northern pole of the needle, and that the positive electricity acts only on the southern —*Annales de Chemie*, August 1820, p. 244— implying a total difference between electric and magnetic fluids, since the magnetic fluid, whether considered as positive or negative, ought to act equally on both poles.

To demonstrate, by experiment, the identity in question, it was necessary to explain all the phenomena—the mutual action of two magnets, the action of a conjunctive wire upon a needle—"without admitting in a magnet any other fluid than the acting electric fluid." This task was undertaken by Ampère. The inter-relationship of electricity and magnetism was further established by Arago who observed that steel needles, placed within spirals of wire, became magnetised when electric discharges were passed through the wire from static electrical machines, or when currents were passed through them from Voltaic batteries.

In the discovery of aluminium, Oersted played a great part, but to Wöhler he had to leave the honour of producing the metal in a pure state. Wöhler, however, recognised the value of Oersted's work in this direction.

Oersted's view was that, given diligence and a healthy brain, advances in natural science can be made even by those of but limited education. It was in accordance with principles of this character that he proposed, in 1824, and founded in 1829, the Selskabet for Naturlaerens Udbredelse—the Society for the popularisation of Natural Science. This he did by giving lectures in the towns, by the distribution of pamphlets, and by supporting those who desired to improve their acquaintance with technical science. The Society still flourishes, and in memory of its founder it has established an Oersted medal as a prize. He realised that the inculcation of scientific principles governing the operations upon which men and women are employed, is a better mission for such a Society than the attempt in schools to teach manual work. He was not an advanced mathematician, but he recognised the necessity for having close enough acquaintance with the subject to enable the results of investigations to be reduced to numerical terms. His dominating idea was the inter-relation between what at that time were called the various forces of the universe; and he saw that the future welfare of his country must depend upon the development of inventive faculties, directed towards the utilisation of natural resources. His plea, therefore, was for technical education strongly supported by natural science. In his wanderings over a wide field, he was led at last by his philosophy into close touch with the basic problems of humanity. Thus he learnt to see life steadily, as well as sympathetically and to see it whole. His influence upon contemporary thought and action finds testimony in Hans Christian Andersen, who confessed to the support and encouragement he received from him.

In 1846, Oersted again visited England, and he was present at the meeting of the British Association at Southampton in that year. The remarks, on that occasion, of Sir John Herschel convey an idea of the impression created upon Englishmen by Oersted, and by his discoveries:

> "To look at his calm manner, who could think that he wielded such an intense power, capable of altering the whole status of science, and almost convulsing the knowledge of the world . . . (his discoveries) went almost to the extent of obliging them to alter their views on the most ordinary laws of force and motion. . . . The electric telegraph, and other wonders of modern science, were but mere effervescences from the surface of this recondite discovery, which Oersted liberated, and which was yet to burst with all its mighty force upon the world."

The fiftieth anniversary of his association with Copenhagen University was on November 7, 1850. At that festival he was greeted by all Denmark, from the King to the most lowly of the people. The Danish Government presented him with a country residence, Fasangaarden in Frederiksberg Park, precious to his memory as the former home of his friend Oehlenschläger. Students in torch-light procession sang verses composed in his honour, and men and women of all ranks and opinions joined with one accord in the festivities. He was then seventy-three years of age, and was actively occupied with lectures and with literature.

During that winter, he busied himself with preparations for the transfer to Fasangaarden, but he never occupied it. He caught cold, and, after a brief illness, died on March 9, 1851.

He was below medium height, of open countenance, of florid complexion, somewhat stout, in manners kindly, by nature gracious, loyal to his King, devoted to his country and to the cause of humanity. In his scientific work he was often baffled but never discouraged, his perseverance helped him to the end. Towards the end, he was able to write to a friend the secret of his life:

> "In my family I am as happy as a man can be. I have a wife whom I love, and children who are dear to me and who prosper. I have three sons—of whom one is of age and is employed in the forestry service of the King—and four daughters, of whom the eldest three are either married or betrothed. My brother, who for some time was a Commissioner for the King in our provincial parliament, has recently become a Minister of State. As for me, I am still a professor and director of the Polytechnic School and Secretary of the Royal Society of Sciences."

Oersted thus had three sons and four daughters. The eldest daughter, Karen, married E. A. Sharling, Professor of Chemistry at Copenhagen. Another daughter, Marie, married S. N. P. Hasle, who for forty-one years was pastor at Odsherred in Zeeland. The youngest, Matilda, remained to cherish her father's old friend Hans Christian Andersen, and to her Andersen bequeathed the manuscripts of his own stories. Oersted's sister, Barbara Albertine, married Georg Jacob Bull, who became President of the Supreme Court of Norway.

His dearest friend, Adam Gottlieb Oehlenschläger (1779–1850) also joined the immortals; with his poems and his sagas he became the great minstrel of the North, who sustained his countrymen with hope and courage in the midst of their tribulations.

In 1920, the Foundation Carlsberg published, under the editorship of Mr. M. C. Harding of the Polyteknisk Laereanstalt, Copenhagen, a collection of Danish, French, German, and a few English letters, representing some of the correspondence of H. C. Oersted with men of science of his time. Mr. Harding has dealt with these documents with such care and precision that they now constitute the best possible means both of judging of the scope and character of Oersted's opinions, friendships, qualities, and achievements, and of observing the variety of ways in which his influence was exerted. From them it appears that, at the threshold of his professional life, Oersted was regarded by some of his scientific acquaintances as *un exalté*, and too empirical, and as something of a dreamer. In 1820, however, when one of his dreams came true, most of his friends—and even the exacting Bezelius—were quick to acknowledge the substantial character of the stuff of which the dreams were made. Erman recognised the discovery of electromagnetism at once at its true worth. Seebeck, on the first verbal account of it, shook his head, but when he read the complete communication he offered "a thousand warmest greetings," and said it deserved a prize like that given by Bonaparte to Volta. Arago, who probably had been acquainted with Oersted for a few years before the announcement of the great experiment, also at first entertained doubts, but became convinced and was the first person in France to direct the attention of scientific men to it. To Switzerland, and to De la Rive, however, belong the credit of the first public demonstration. In England, on November 16, 1820, at the Royal Society, Davy assigned to Oersted the honour of priority in the discovery of electromagnetism, and declared that no anterior experiments by others could change the fact of that priority. His opinion of Oersted is also recorded—"He is chiefly distinguished by his discovery of electromagnetism. He is a man of simple manners, of no pretentions, and not of extensive resources; but ingenious, and a little of a German metaphysician." Faraday for once confessed that chance counted for something; but he was convinced of the originality of Oersted's experiment. He said of Oersted: "His constancy in the pursuit of his subject, both by reasoning and experiment, was well rewarded in the winter of 1819 by the discovery of a fact of which not a single person beside himself (Oersted) had the slightest suspicion, but which, when once known, instantly drew the attention of all who were able to appreciate its importance and value."

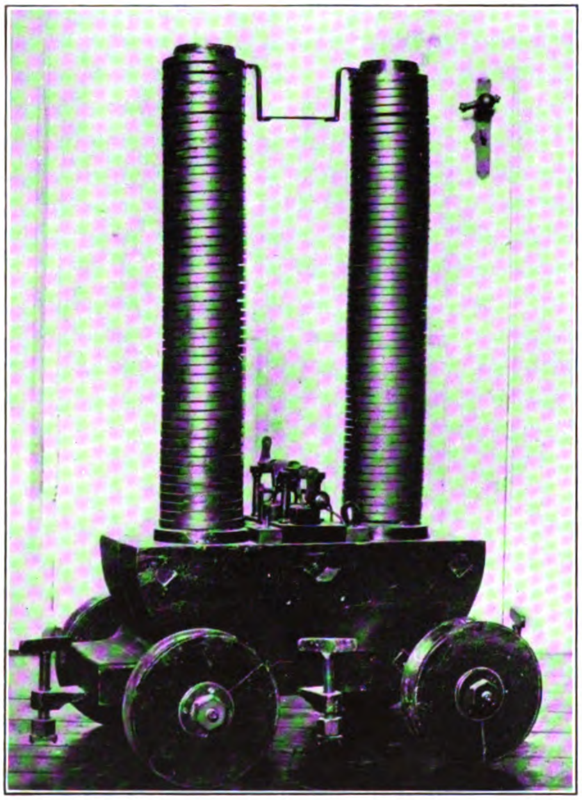


Figure 8—H. C. Oersted's Electromagnet, Constructed After He Had Seen Faraday's Electromagnet. The height of the magnet cores was about 50 centimetres.

Oersted and Faraday met for the first time in London in 1823. Owing to the subordinate position of Faraday to Davy, Oersted could not then get into direct touch with him. It was therefore under conduct of Davy that Oersted took part in some experiments of Faraday, that year, at the Royal Institution. In 1846, when Oersted for the second time visited Faraday's laboratory, his attention was given to the great horse-shoe electromagnet. At that time Faraday was not present, but his old laboratory assistant acted as guide. After the 1846 British Association Meeting, however, Faraday himself showed Oersted his experiments on diamagnetism. Upon his return to Copenhagen, Oersted constructed an electromagnet (Figure 8) which is still preserved in the Polytechnic School. With it, in 1847, he demonstrated Faraday's experiment in diamagnetism at the Royal Académie of Copenhagen, and he continued that work until 1849. The two philosophers followed closely the accounts of one another's researches on such subjects as compressibility, the validity of Mariotte's law, the liquefaction of gases, and the formation of sonorous figures on vibrating plates.

Of all the congratulations he received from men of scientific perception, the most emphatic were those of Dr. Thomas Young who spoke of the marvellous discovery that elevated Denmark to a rank in science which it had not held since the days of Tycho Brahe. In Germany, the learned Dr. J. S. C. Schweigger paid no less a tribute when he declared that Oersted's experiments in magnetism were the most interesting that had been carried out in that domain of science for a thousand years. Concerning telegraphy Schweigger, in 1848 wrote to Oersted:

"Sir waren es, mein verehrter Freund, dessen Elektromagnetismus die engste Verbindung der Menschen herbeigeführt durch die nun so Zahlreich angelegten electromagnetischen Telegraphen. Statt sich dieser engen Verbindung zu freuen, fangt man Kriege an und entzweit selbst die durch Abstammung, Sprache und Sitte von Natur befreundeten Völker, wie Dänen und Deutsche."

(It was you, my honoured friend, whose electromagnetism made the close bond between men, by means of the now numerous forms of electromagnetic telegraphy. But instead of this bond being a cause for rejoicing, it has begun to be a means of war and separation of languages and customs of friendly peoples like the Danes and the Germans.)

The first in America to emphasize the importance of Oersted's discovery of electromagnetism was Joseph Henry (Transactions of the Albany Institute, Vol. 1, pp. 22–24, 1830). By 1841 the name of Oersted was as well known in America as in any part of Europe.

The impression created by the researches of Oersted is that his greatest successes were derived from experiment. Even in 1801 he was seeking to improve his powers as an experimenter by learning glass-blowing in Leipsic, and a year or two afterwards he was at Haarlem repeating Ritter's experiments in company with Van Marum. In 1846 he observed with enthusiasm the experiments of Faraday. It is curious to observe, therefore, that in 1849, when he was approaching the last stage of his career, he confessed, in a letter to Sir John F. W. Herschel, that he had continuously turned his mind against the results which could be drawn from the experimental sciences to those which are commonly treated as depending particularly upon mental powers. He added: "I am far from approving the German metaphysics. . . . I have long since been led to form a philosophy of my own . . . through the corporal world to the mental." The truth is that like all who seek earnestly to penetrate the laws of nature, he developed a mind inherently unstable but maintained in equilibrium by perpetual spin and oscillation between fact and opinion, experiment and enlightened imagination, the never and forever of all time.

It is in his friendship for Ritter that his finest qualities appear. He met him first in 1801 when Ritter's work was little known. In March, 1803, in Paris, Oersted gave a demonstration of Ritter's invisible (ultra-violet) rays that could act chemically, and in May of that year he did the like for Ritter's secondary cell. Biot thereupon asked Oersted to obtain from Ritter a direct communication upon these subjects, and it was because of it that Ritter, obscure, reserved, eccentric, and impoverished, obtained the prize of 3000 livres. Ritter in 1802 was working every day for months from 9 A.M. to 10 P.M. with the Duke of Gotha's mammoth battery of 600 pairs of plates. Chemistry, he truly said, takes a long time. His experiments with a zinc-silver needle on a pivot led him into strange fancies, and his magnetic battery, consisting of a series of watch-glasses containing water and united each to the next by a series of bent magnetised steel rods, must have puzzled even Humboldt. Ritter promised himself a "recht magnetschen Winter," but he became involved instead in an assemblage of paradoxical phenomena concerning which he appealed constantly to Oersted. Then he visited Italy, and kept Oersted informed of what was happening there with regard to alleged animal "magnetism," water-finding, mineral-finding, and other pseudo-scientific matters, the results either of deception or of lack of precise means of analysis. In due course came the battle of Austerlitz. Ritter wrote to Oersted on December 8, 1805, telling him of the losses sustained, and of his privations.

"München schickt sich unterdessen immermehr zu einem Kriegstheater an, weil heir ein Hauptübergang über die Isar ist. In wenig Tagen sind wir höchst wahrscheinlich den Kuglen des Geschützes ausgesetzt. Die franz. Vorposten sollen bereits in Augsburg seyn."

(Munich is meanwhile becoming more and more a theatre of war, because here there is an important crossing of the Isar. In a few days we shall probably be blown sky high by the cannon-balls of the artillery. The French advanced troops are already at Augsburg.)

"Thank God," he added, "experiments don't cost much." His highest hope was that Napoleon would visit the Akademie at Munich—the Empress Josephine was already in that city. This aspiration concluded—

"Von meiner Seite soll er dann hier sehen, was er in Bologna bloss gehört hatte. Lebe wohl."

Ritter told Oersted that he desired to talk to Volta about the possible electrical origin of animal magnetism, but

"Gegen Leute, wie Er, muss man höflich seyn, u. nach ihrer Sprache bequemen."

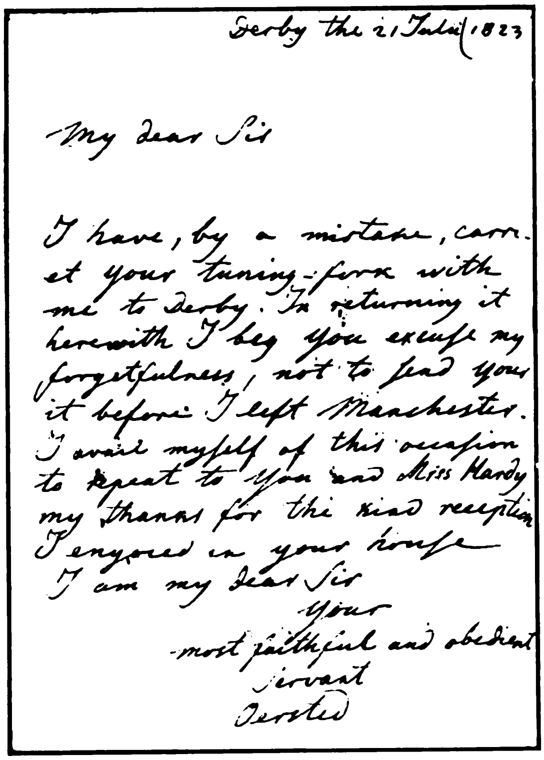
(With people like HIM we must be polite, and mind what we say.)

Behind all this there was Ritter's poverty and his endeavour to find relief by winning the French prize. He wrote piteously to Oersted for assistance,

> "Geld ist dass was mir fehlt, u. was mir mehr fehlt, als es nur je gefehlt hat."

and reading between the lines of this correspondence it becomes obvious that Oersted aided him with his accustomed generosity. On the other hand Oersted absorbed some important home truths from Ritter, and especially to temper existence with harmony and colour. Ritter chaffed him about the rigidity of his philosophy, and added

> "Vergiss nicht, dass wir Künstler seyn sollen. Kunst aber brauche ich dir nicht zu definiren."



Derby the 21 Julii 1823

My dear Sir

I have, by a mistake, carr-
et your tuning-fork with
me to Derby. In returning it
herewith I beg you excuse my
forgetfulness, not to send you
it before I left Manchester.
I avail myself of this occasion
to repeat to you and Miss Hardy
my thanks for the kind reception
I enjoyed in your house —
I am my dear Sir
Your
most faithful and obedient
servant
Oersted

Specimen of H. C. Oersted's Handwriting. It is a copy of a letter sent to a Mr. Hardy when H. C. Oersted was in England in 1823.

(Don't forget that we are artists—but I need not define art for you.)

Ritter was perplexed about magnetism; it seemed to him to belong to the other side of nature and to lead to the under-world. Its laws appeared to be opposed to all ordinary laws. He hoped, however, some day to resolve doubts by raising all metals to the magnetic rank of iron, possibly by extreme cold or by extreme heat.

The speculations of Winterl, in 1800, concerning chemical action, made upon Oersted a profound impression. It was Winterl who introduced the two subtle conceptions Andonia and Thelyke—elements more simple than all others, but entering into all. Oersted was captivated by the idea, but he found at Berlin a "terrible prejudice" against it, for Andonia and Thelyke were there denounced as phantoms. From such airy nothings, however, was spun thus early his imaginative faculty, and, above all, the enthusiasm that carried him unscathed across the turbulence of his time.

By his travels and by his close study of contemporary scientific writings, Oersted kept himself informed of progress and utilised his knowledge for the good of his country. He could not always hasten the advance as much as he wished. For example, he was aware in 1811 of the existence of gas lighting (thermolampe)[1] but although it was in evidence in London in 1812, Stockholm waited for it until 1853, and Copenhagen until 1857. After a visit to Gauss at Göttingen in the summer of 1834, he established a magnetic laboratory in a wooden shed in the garden of the Polytechnic School at Copenhagen, and later upon the ramparts of that city. He was a friend of Hansteen, and on his journeys through Europe he introduced Hansteen's apparatus for the observation of terrestrial magnetism. It was in fact at the instigation of Oersted that Arago used it in Paris.

The chief object of his journey in 1822–1823 was to discuss optics, with Seebeck in Berlin; Frauenhofer at Munich; Biot, Fresnel and Arago in Paris; Wollaston, Young and Herschel in London; and Brewster in Edinburgh. Another matter investigated was whether, in accordance with Halley, the earth had four magnetic poles, or whether, as propounded by Euler, it possessed only two, and those unequal. Other puzzles were the causes of magnetic variation and of the polar lights. There was also under consideration the alleged observation by Maschmann that the crystallisation of silver from the solution of the salt is more effective in the magnetic meridian. Later, like most of the pioneers, Oersted directed his attention to the atomic theory, to the dynamics of space and to cohesion.

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[1] William Murdoch's first trial of coal-gas, in his home at Redruth, was in 1779. His first installation of gas lighting was at the works of Phillips and Lee, of Manchester, in 1807.

In 1839, Christian VIII (1786–1848) succeeded his uncle upon the throne of Denmark. He set the finances in order and in general he ruled well. In 1842 he became president of the Royal Society of Sciences at Copenhagen, of which Oersted was secretary. Occasionally the King took the chair at the meetings, but in any case it was Oersted's duty to hand to him a report of all that transpired, and this brought the philosopher and the monarch into constant touch—a circumstance that proved of advantage to the cause of natural science in Denmark. It also facilitated the bestowal of honours. Sir John F. W. Herschel, who became a Knight Commander of Dannebrog, was not allowed to wear the Order in England. This, however, did not deter Sir Roderick Murchison from entering the lists. His birthplace was Scotland, and in reply to preliminary interrogatories he said that, if His Majesty, King Christian, should be pleased to confer any Order on him, it would not be necessary for the case to be tried as he would simply wear the Order. And he did.

Oersted's opinion on the broad issue was: "I cannot but feel the ludicrous in all these titles and distinctions, but I am somewhat reconciled to them by the consideration that they seem to counterbalance the aristocracy of birth and of money. Some day to come will bring a better balance between the honours and merits than this, but I apprehend that this day is not very near."

The friendship between Oersted and Sir David Brewster began at the end of June, 1823, at Edinburgh, where Brewster introduced him to Sir Walter Scott and to other celebrities. In consequence of this visit, Oersted wrote several articles for the Edinburgh Encyclopaedia. They met for the last time at the meeting of the British Association at Southampton in September, 1846. The financial position in Denmark was then serious. Oersted probably lost heavily, and was anxious to restore his income by the sale of his books and writings in England. Yet he always had entertained a poor opinion of publishers—in 1803 he described them as unhappy mortals who understand nothing of the contents of what is offered to them and who depend solely upon the name of the writer. This opinion was strengthened when Mr. Longman refused to publish an English edition of his book on the Philosophy of Beauty. In Danish, German, and French he was a concise writer and prided himself upon the quality of his productions. In English he was fluent but less perfect. Writing, in any case, was not a pleasure to him. "I write," he said, "as if I had to pay for every line. I know some men who write as if every line were to be paid for by others"; and he confessed to "a singular disinclination to writing letters, which has often excited my own astonishment." Nevertheless in 1805 he contemplated writing a Book of Physics for Ladies, and he would have done it if Ritter had not dissuaded him by ridicule.

H. C. Oersted from an Engraving by A. Weger, in Leipsic.

For Charles Wheatstone, Oersted had considerable regard. The two men had much in common. It is stated by Mr. M. C. Harding that, in 1823, on the occasion of Oersted's visit to London, Wheatstone had just opened a musical-instrument shop where he carried out acoustic experiments so much appreciated by the Danish physicist that Oersted himself introduced Wheatstone to Sir John Herschel and to Babbage. Moreover, it was Oersted who, in 1823, made known in Paris the acoustic and other experiments of Wheatstone; and it was to Oersted that, on May 20, 1839, Wheatstone wrote from King's College, London, describing:

> "The way in which I have applied your beautiful discovery for the purpose of transmitting instantaneously, both visibly and audibly, to great distances. The first Electrical Telegraph was established by Mr. Cooke and myself on the London and Birmingham Railway in the year 1837, and we have now a line in action 14 miles in length on the Great Western Railway between London and Bristol."

And on August 16, 1844, from the same address:

> "The Electric Telegraph is being brought into extensive use. Our Government has just decided on establishing a line between London and Portsmouth and a commencement is being made in France on the Paris and Orleans Railway."

Miss Petraea Sharling, the gifted daughter of Professor Sharling, has kindly furnished from memory some of the personal details for this account of her grandfather. To Mr. M. C. Harding, and to other members of the Administration of Copenhagen University, thanks are due for many other details, and for kind assistance in obtaining illustrations.

London Toll Exchange

By E. A. ELLIMAN

Engineering Department, Standard Telephones and Cables, Ltd.

Introduction

SIX years ago the Toll exchange in Norwich Street, near Fetter Lane, London, was opened to relieve the London Trunk exchange of the traffic between London and provincial exchanges within an approximate radius of 25 miles and to facilitate the handling of this traffic with greater despatch. The result has been that telephone subscribers in the home counties have been given a very satisfactory no-delay service. In addition, pressure on the London Trunk service has been relieved to an extent such that the long distance switching development has been facilitated considerably and busy London exchanges have been freed from an appreciable load of tandem switching.

With the object of extending the range and advantages of the London Toll service, the British Post Office shortly will open a new exchange[1] at G. P. O. South, Carter Lane, which will work in conjunction with the present equipment in Norwich Street. Both equipments have been manufactured and installed by Standard Telephones and Cables, Ltd., London.

A map of the Toll area is shown in Figure 1, the continuous line embracing the exchanges served by the Toll exchange in Norwich Street, and the extensions to the area resulting from the introduction of Toll G. P. O. South being indicated by the dotted line protrusions from this boundary. It will be observed that three additional areas, all having a large community of interest with London, will receive Toll facilities due to the opening of Toll G. P. O. South—Southend and Chatham districts on the East, Aldershot district on the West and Horsham district on the South.

Before proceeding with a description of the new equipment at G. P. O. South and the new conditions which its opening will involve, a brief description will be given of the existing Toll exchange at Norwich Street and its operating procedure.

Toll Exchange, Norwich Street

The switchboard is of the No. 10 common battery type provided with automatic signaling facilities and consists of three distinct groups of positions—one known as "Control" positions, arranged for handling traffic from London local exchanges to provincial towns in the Toll area; another known as "Incoming" positions for traffic incoming from the provincial towns for London local exchanges; and the third, known as "Trunk Junction" positions, for calls incoming from London Trunk exchange.

Signal junction lines are provided for traffic outgoing from London local exchanges to the Toll exchange, these lines terminating at the Toll operating positions in jacks and lamps, similar to the answering equipment at subscribers' positions of a local exchange.

A complete multiple of outgoing Toll lines and junctions outgoing to the London local exchanges is provided throughout the Toll exchange. This is available to every operator so that, if circuits are free, a connection between a London local subscriber and a provincial subscriber in the area can be completed without delay in either direction. Calls which cannot be completed on demand are booked and the connection established as soon as the lines are free, the London subscriber ultimately being called and connected over the outgoing junctions from the Toll exchange.

Traffic from the Toll exchange to the London local exchanges is circulated over groups of order-wire junctions or signal junctions which are connected to the incoming positions at the local exchanges like ordinary local junctions.

Toll lines incoming from the Provinces are terminated in lamps and jacks at the Toll operating positions, like jack-ended junctions or subscribers' lines.

Traffic passing through both the London Trunk exchange and the London Toll exchange is circulated over groups of order-wire junctions. These junctions terminate at the London Toll exchange on special positions similar to incoming order-wire positions at local exchanges.

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[1] The new exchange was successfully brought into service on December 4, 1927.

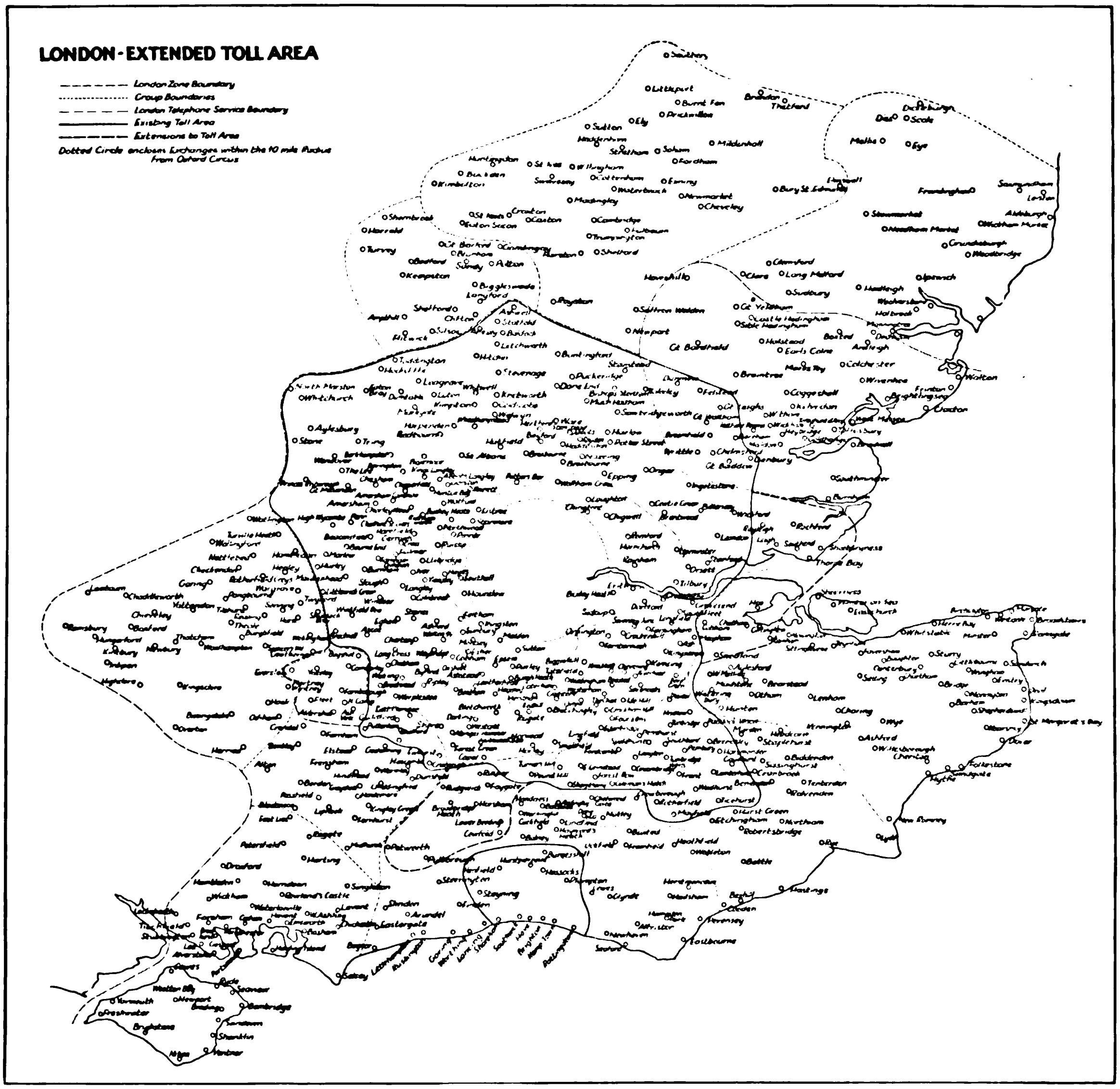

LONDON - EXTENDED TOLL AREA
London Zone Boundary
Group Boundaries
London Telephone Service Boundary
Existing Toll Area
Extensions to Toll Area
Dotted Circle encloses Exchanges within the 10 mile Radius from Oxford Circus

Figure 1

Operating Procedure Previous to Opening of G. P. O. South

I. *Controlled Traffic*

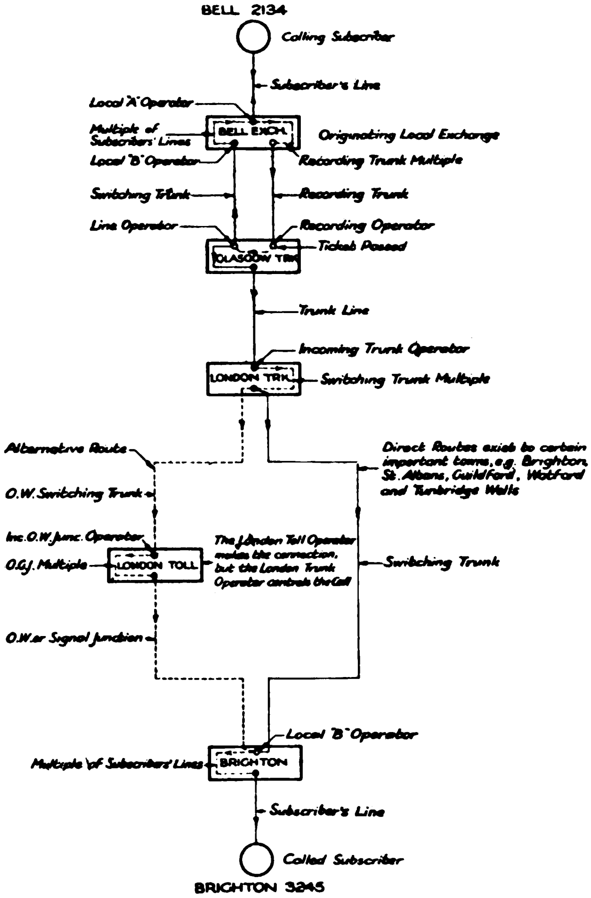
All calls originated by London subscribers for exchanges in the existing London Toll area are controlled at the Toll exchange—Norwich Street. The calling signal is received at a Toll operating position and the line is challenged by the operator, who says "Toll—Number please." The subscriber gives his own number and the number of the required subscriber. The Toll operator writes these particulars on a ticket, repeating them to the subscriber for confirmation or correction. She tests for a disengaged Toll line with the tip of her calling plug and enters the first free line. The provincial operator is signaled automatically by the plugging in to the jack and answers by giving the name of her exchange. The Toll operator passes the number of the subscriber wanted and the provincial operator makes the connection and rings out on the subscriber's line.

When the subscriber required is connected to an exchange subsidiary to that at which the Toll route terminates, the Toll operator asks the provincial Toll centre for the exchange required and waits till the operator at the distant end answers, before passing the number required. When the distant subscriber answers, the London Toll operator satisfies herself that the two subscribers are able to converse satisfactorily and retires from the connection by restoring her listening key to its normal position. She then writes on the ticket the time that the conversation commenced, places the ticket in the clip in front of the cords used to make the connection, and supervises the call.

Should the conversation last three minutes, she enters the circuit and announces that the time is expired and offers an extension if required. If an extension of time is desired, the ticket is marked accordingly and the connections maintained for another three minutes, the procedure being repeated at the end of that period. No limit to the period of conversation is imposed, unless delays occur on the Toll route, in which case operators are instructed to refuse demands for extensions beyond six minutes.

At the completion of the call, the ticket is withdrawn from the clip, marked with a charge tick and placed in the tray for completed call tickets.

Booked Calls. When it is necessary to book a call, the time at which the demand was made is recorded in the "Booking Time" space on the ticket which then is placed in the delayed call ticket receptacle provided at each position. The subscriber is advised that Toll lines are engaged and that he will be rung later. The operator makes attempts at frequent intervals to secure the Toll line required, noting the time of each attempt on the ticket. As soon as the Toll line is free, she secures it and passes the required subscriber's number and then proceeds to obtain the London subscriber over the outgoing junctions.



ROUTING OF A TYPICAL TRUNK TO TOLL CALL
BELL 2134 *requests* BRIGHTON 3245

Figure 2

Delays. When, owing to the engagement of Toll lines, a call is delayed for 30 minutes the operator, after trying all alternative routes in vain to complete the call, notifies her supervisor. All calls waiting for a route are ticketed and the tickets circulated to the Special Delay position for attention. The handling of these calls will be described later under the heading of "Delayed Traffic."

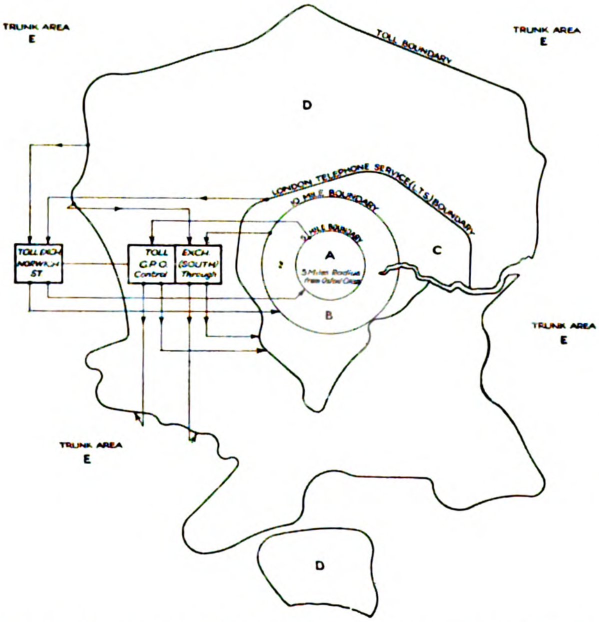


Figure 3—Skeleton Map of Telephone Areas Indicating Routing and Control of Traffic after Opening of Toll (G.P.O. South) and Tandem Exchanges. (See also Table No. 1.)

Signaling Arrangements. When a connection is given on demand and the conversation is held over the junction on which the demand was received, the answering supervisory signal does not glow until the junction is cleared at the local exchange. The calling subscriber's supervisory signal is received by the local operator, who clears the junction to the Toll exchange.

When a call is booked and subsequently effected over the outgoing local junction multiple, the London subscriber's supervisory signal is received direct on the answering supervisory lamp. In the majority of cases, a clearing signal is received direct from the provincial subscriber. In order that the other cases may be provided for, close supervision is exercised on all calls.

II. *Incoming Traffic*

No record of incoming provincial traffic is kept at the Toll exchange in Norwich Street.

The operator, on observing a line lamp glow, inserts an answering plug into the corresponding jack and challenges the line with the remark "London." Receiving details of the required connection from the distant operator, she repeats them and proceeds to secure the connection to the local exchange over the outgoing junctions.

The control of all traffic on incoming Toll lines rests with the provincial operators, who, in cases of "No Reply," "Line Engaged," etc., are responsible for any further attempts to complete the calls. After establishing the connections for an incoming call, the Toll operator does not enter the circuit again, unless a flashing or clearing signal is received.

Supervisory Signals. The answering supervisory lamp is darkened when the Toll operator answers and remains dark until the Toll line is released at the provincial exchange.

The calling supervisory lamp glows when an order-wire junction is picked up and darkens when the London subscriber answers. It glows again when the London subscriber hangs up his receiver.

When a signal junction is used, the calling supervisory lamp darkens when the distant operator answers and glows again when she leaves the circuit, continuing to glow until the called subscriber answers or the distant operator enters the circuit again.

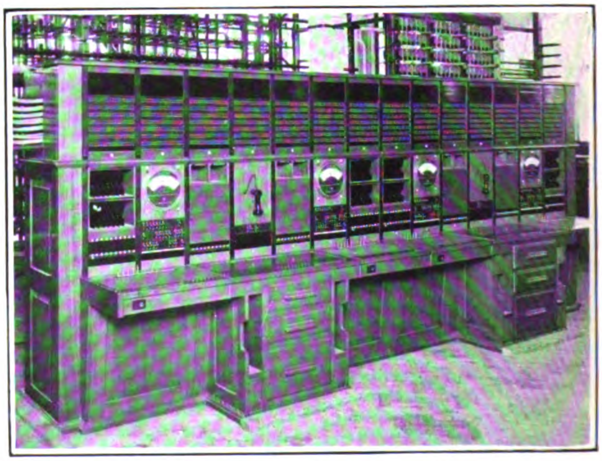


Figure 4—Test Desk, Toll Exchange G.P.O. South.

The signals given by the London subscribers are received at provincial common battery exchanges, but not at magneto exchanges.

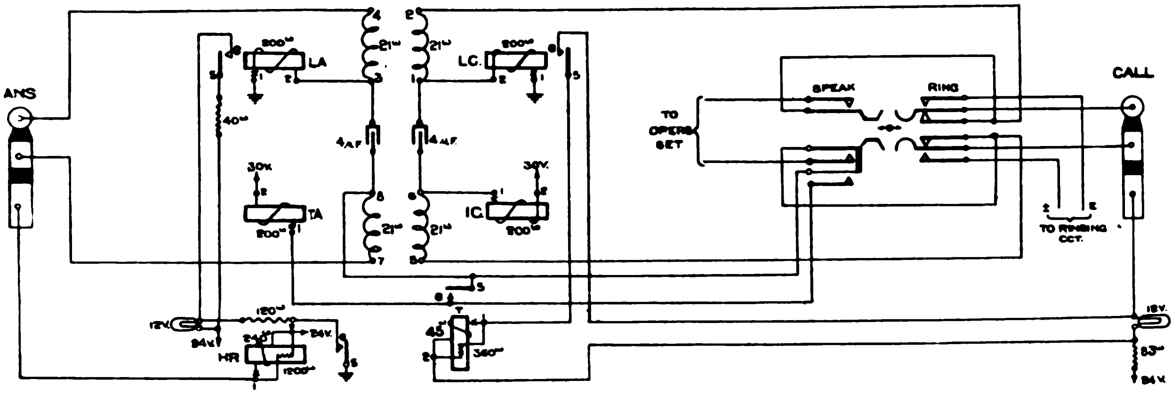


Figure 5—"B" Cord Circuit.

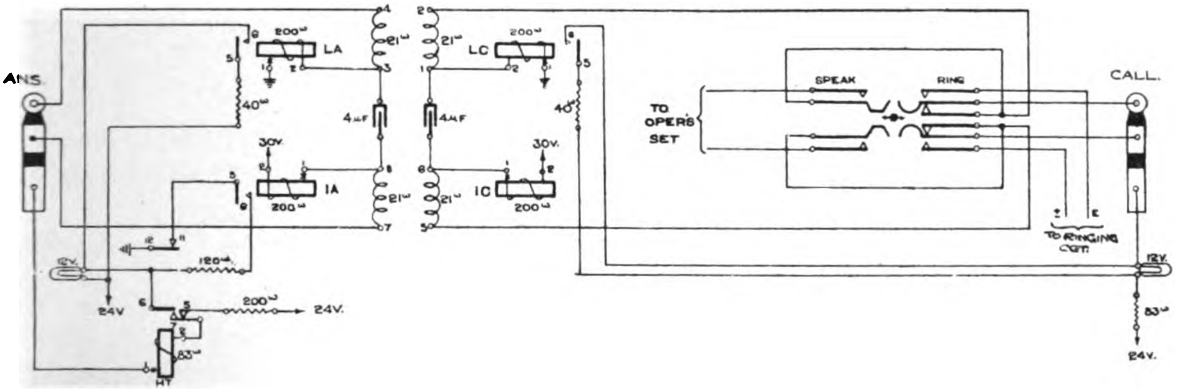


Figure 6—Control Cord Circuit.

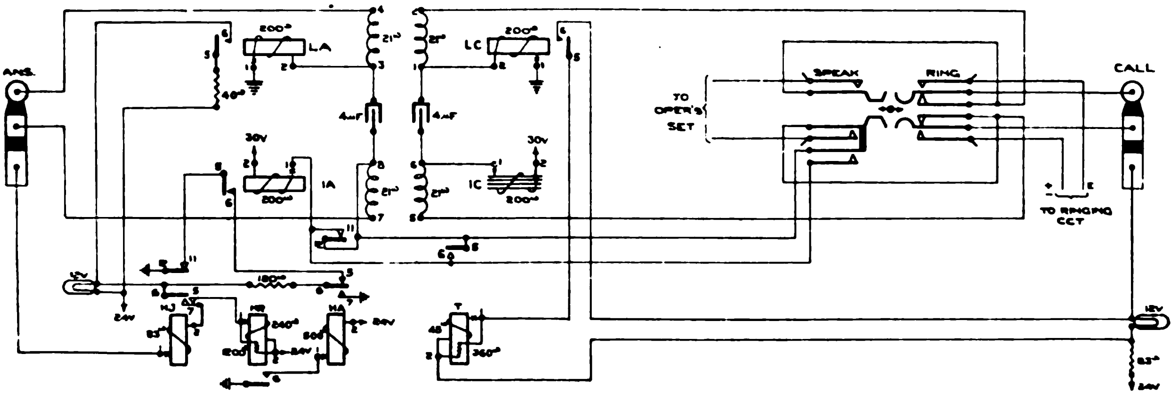


Figure 7—Universal Cord Circuit.

Double Clearing. Upon receipt of clearing signals on both supervisory lamps, the connections are broken down without challenge.

Single Clearing. (*a*) Answering (Provincial) Supervisory: The Toll operator enters the circuit saying, "Have you finished?" Receiving no reply, she breaks down the connections. If the London subscriber is still on the line and complains that he has not spoken or that he has been cut off, the operator instructs him to replace his receiver, stating that he probably will be called again. (*b*) Calling (London) Supervisory: The Toll operator challenges the line and, receiving no reply, breaks down the connection.

Through Provincial Calls. (*Tandem Working*). Calls incoming from provincial exchanges for other provincial exchanges in the London Toll area are handled at the incoming Toll positions. If a Toll line to the required exchange is available, the connection is given at once; otherwise, the busy back signal is given. These through calls are controlled at the originating provincial exchange, the London Toll exchange functioning in this case as a tandem office.

On the receipt of a signal on the answering supervisory lamp, the Toll operator challenges the line and breaks down the connection.

Calls from Provincial Exchanges Routed by London Toll to London Trunk Exchange. Provincial operators connected with London Toll exchange requiring an exchange in the London Trunk area ask the Toll operator for "Zone Records." The Toll operator tests for a disengaged line in the group of zone record junctions, which is located in the outgoing local junction multiple. Finding a disengaged junction, she completes the connection, thus putting the provincial operator into communication with the record operator at the London Trunk exchange.

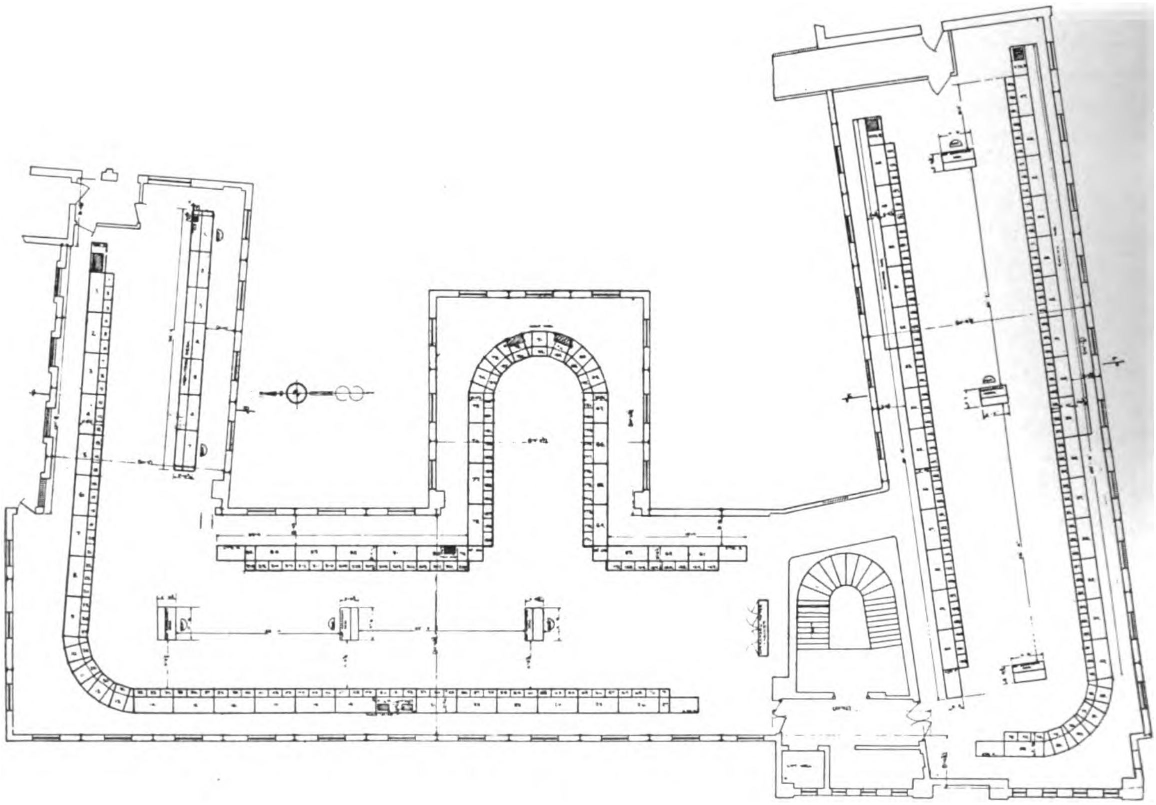


Figure 8—Layout of Switchboards and Desks, Toll Exchange G.P.O. South.

III. *Trunk to Toll Traffic*

The calls handled at the special positions provided for this traffic may be divided into two classes:

(1) Calls originating at provincial exchanges outside the London Toll area for provincial exchanges served through London Toll exchange.

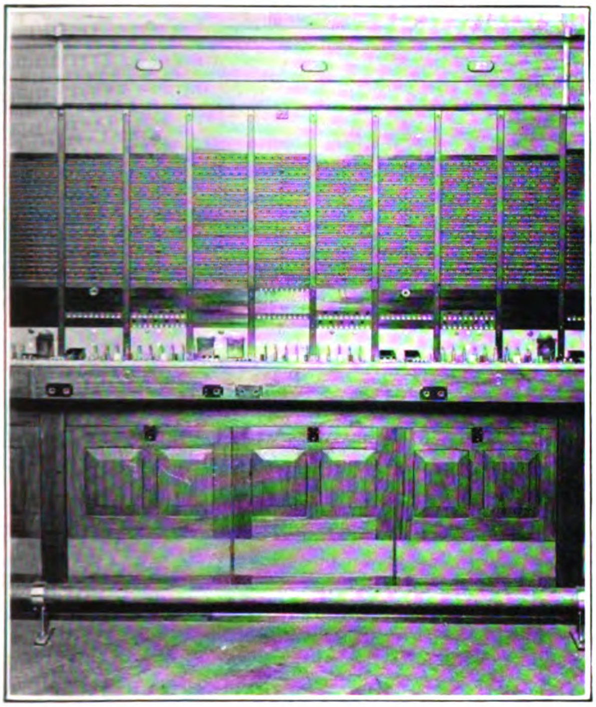


Figure 9—Typical Section of "Control" Positions—Front View—Toll Exchange G.P.O. South.

(2) Calls originating at exchanges in the London Toll area for provincial exchanges served through London Trunk exchange. As already mentioned, calls in this class are routed by Incoming Toll operators to zone records. The record is made at the Trunk exchange and, where direct lines from the Trunk exchange to the town required do not exist or for any reason are not available, the call is reversed, re-entering London Toll by the special positions considered in this section. This means that these calls are now handled in exactly the same manner as those in Section I (Controlled Traffic).

The Trunk junction operator at London Toll receives a demand over the order-wire for connection to a provincial exchange in the London Toll area. She allots a junction to the Trunk operator and proceeds to test for a disengaged line in the Toll route required. If a line is available, she makes the connection with the junction allotted without ringing on the Toll line and leaves the Trunk operator to pass the number and control the call. If a Toll line is not available, she connects the junction allotted with the "Engaged" signal.

Should the delay procedure be in operation on the Toll line demanded, she connects the junction allotted with a delay operator at London Toll, who completes the connection as soon as a line becomes available.

Figure 2 illustrates the sequence of events in routing a call from a subscriber in Glasgow to a subscriber in Brighton, showing alternative routes:

(1) Through London Trunk exchange and direct junction to Brighton.

(2) Through London Trunk exchange and London Toll exchange.

The arrow heads indicate the direction in which the connection is being established.

Supervisory Signals. Each incoming junction circuit is provided with a supervisory lamp, which is controlled by the operator at London Trunk exchange. Upon receipt of the clearing signal on this supervisory lamp, the Trunk junction operator at London Toll breaks down the connection.

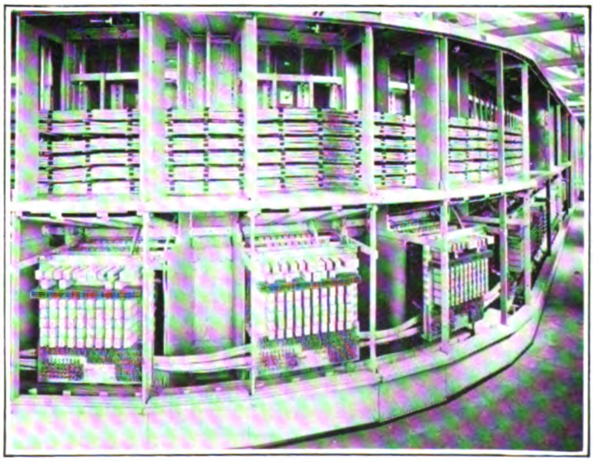


Figure 10—Rear View of Control Positions in South Wing.

IV. *Delayed Traffic*

When the delay on a Toll route amounts to 30 minutes, the Toll operator books the calls received and circulates all tickets for that route to the delay positions. The delay operators take control of all such routes and connect the calls in the booking time order. As soon as the delay is reduced to 5 minutes, the Toll operators are instructed to resume control.

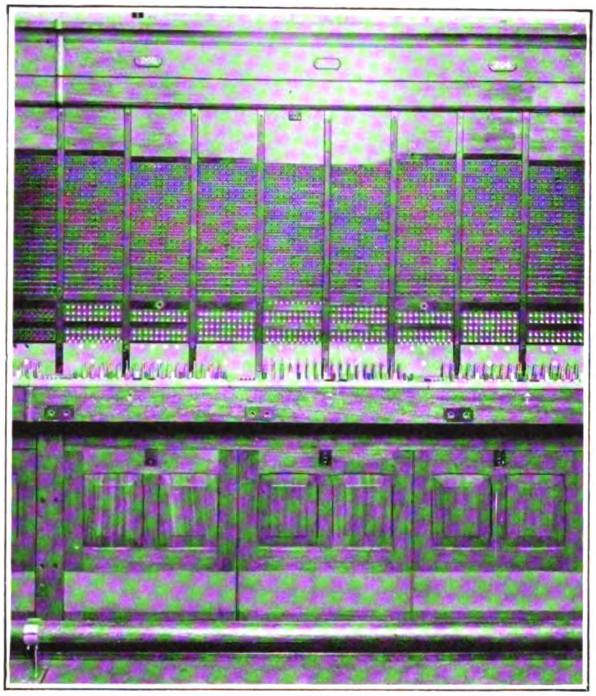


Figure 11—Typical Section of "Through" Positions.

The Toll operator at an incoming position, receiving a call for a "Delay" route, connects the junction allotted to a transfer line terminating at one of the delay positions. The delay operator, upon receipt of a calling signal on the transfer line, enters the circuit and enquires the name of the wanted exchange. If the route desired is available at the position, she appropriates the first free line for the call and through the section supervisor arranges for the Trunk-toll junction to be transferred from the transfer line to the Toll line appropriated.

If the Toll route concerned is under the control of another delay operator not adjacent to the one who answers the transfer line signal, the operator answering the call furnishes her section supervisor with the name of the route in which a line is required and the number of the transfer line.

The supervisor arranges for the appropriation of a Toll line and for the transfer of the junction to that line.

INFORMATION SERVICE

Facilities are provided to furnish an efficient information service.

The equipment for this purpose consists of two four-position desks fitted with the following circuits:

(*a*) Lines incoming from the switchboard terminating in lamps and jacks. (Complaint lines, enquiry lines, etc.)
(*b*) Lines outgoing to a control position
(*c*) Lines for transferring calls from position to position at the information desk
(*d*) Lines to the supervisors
(*e*) Lines for communicating with each position operator in the exchange
(*f*) Bothway lines to information desks at other exchanges.

All lines are multiplied so as to be accessible to every operator at the information desk.

Class of Calls

The calls handled at these positions are those of an irregular nature received by the Toll operators as, for example, calls for supervisor, fee enquiries, directory enquiries, and information or complaints relating to service.

As far as possible, the Toll operator receiving such calls differentiates between complaints and enquiries, and connects the subscribers to the appropriate lines going to the information desk. Assistant supervisors usually attend to complaints, whilst the work of enquiries is generally handled by senior operators.

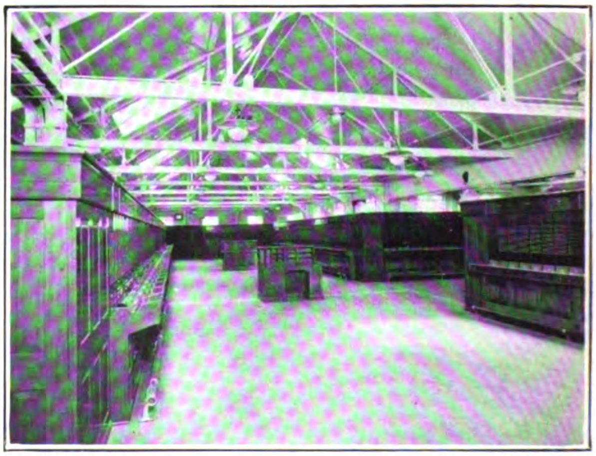


Figure 12—Operating Room—General View Facing North —Toll Exchange G.P.O. South.

Procedure

Every complaint or enquiry is recorded on a docket and dealt with according to its merits. Where it is necessary to give the subscriber a connection on the Toll system, it is not effected through the information desk but through the Toll switchboard in the regular manner, thus obviating transmission difficulties.

TABLE I

ROUTING AND CONTROL OF TRAFFIC AFTER TOLL (G. P. O. SOUTH) AND TANDEM EXCHANGES ARE OPENED

A—Exchanges within the 5 mile circle
B— " between the 5 mile circle and the 10 mile circle
C— " outside the 10 mile circle and within the L. T. S. area
D— " outside the L. T. S. area and within Toll area
E— " in Trunk area

From	To	Route	Control	
			Automatic	Manual
A	A	Direct or via Tandem	Dialed by Subscriber	Originating Local Ex.
A	B	" " " "	" " "	" " "
A	C	Toll (G. P. O. Sth.) or Direct	Toll Exchange	" " "
A	D	" " "	" "	Toll Exchange
B	A	Direct or via Tandem	Dialed by Subscriber	Originating Local Ex.
B	B	" " " "	Unit Fee: Dialed by Subscriber Excess Fee: Originating Local Ex.	" " " " " "
B	C	Toll (G. P. O. Sth.) or Direct	Originating Local Ex.	" " "
B	D	" " " " "	" " "	" " "
C	A	Initially Tandem or Direct Ultimately Toll (Norwich Street) or Direct	" " "	" " "
C	B			
C	C	Toll (G. P. O. Sth.) or Direct *	" " "	" " "
C	D			
D	A	Toll (Norwich St.) or Direct	" " "	" " "
D	B			
D	C	Toll (G. P. O. Sth.) or Direct	" " "	" " "
D	D			
A, B & C	E	Direct or Tandem to Trunk Records	" " "	" " "
D	E	Toll (Norwich St.) or Tandem to Trunk Records	" " "	" " "
E	A & B	Trunks by Direct Junction or via Toll (Norwich St.)		
E	C	Trunks by Direct Junction or via Toll (G. P. O. Sth.)		
E	D	Trunks by direct line to objective exchange or switching centre		

* Or in some special cases via Local Toll Centre.

New Toll Exchange—G. P. O. South

EFFECT ON TOLL AREA TRAFFIC

It is anticipated that the British Post Office will open its Tandem exchange in London at the same time that the Toll G. P. O. South equipment is placed into service, and the routing and control of telephone traffic then will be arranged as indicated in Table I and Figure 3. The control of the Toll area traffic at this period will be divided between the two centres, Norwich Street and G. P. O. South, the Norwich Street exchange handling the traffic from the provincial towns in the Toll area to exchanges within the 5 and 10 mile circles with Oxford Circus as the centre, and from the London telephone service area to exchanges within the 5 and 10 mile circles. In fact, all calls for subscribers within these two circles passing through the Toll area will be completed at the Norwich Street exchange, since the multiple of junctions to the London exchanges is located at this exchange and not at G. P. O. South.

At London Toll exchange G. P. O. South, four classes of traffic will be handled:

1. Controlled traffic; i.e., calls from London subscribers within the 5 mile circle to the Toll area

2. Through Calls:
   - (*a*) Calls from subscribers between the 5 and 10 mile circles to places within the Toll area. Modification may be made later to include these calls with controlled traffic.
   - (*b*) Calls between places within the Toll area.
3. Trunk to Toll traffic where direct circuits to places in the Toll area are not provided from the Trunk exchange multiple
4. Delayed traffic, the local London subscriber being obtained in this case via Norwich Street, as already explained, although the actual booking will be done at G. P. O. South.

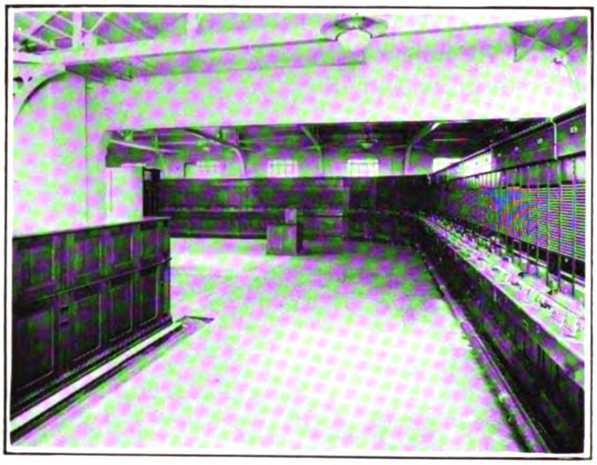


Figure 13—Operating Room—North Wing.

OPERATING PROCEDURE

It is expected that the operating procedure will be very similar to that at present in force at the Toll, Norwich Street exchange, and it is very probable that the information service will be centralised at the G. P. O. South exchange, where a 14-position monitor's desk is installed.

EQUIPMENT

The new Toll equipment is accommodated in the building which also contains the London Trunk exchange and the two local exchanges known as "City" and "Central," respectively.

The power supply at 24 volts will be received from the Central exchange batteries and a supply at 30 volts will be derived from additional cells provided by the Post Office. Ringing current will be furnished to the exchange by the Central exchange ringing machines. Additions and modifications to City and Central power plants for battery charging purposes have been carried out under the contract for the Toll exchange. The 24-volt supply will be fed by twin concentric lead-covered cables running from the basement to the third floor, where they are terminated at a bifurcating box located on the wall of the repeater room.

The apparatus room is located on the fourth floor and contains the repeating coil rack and fuse panel, the intermediate distributing frame, two relay racks and the time check rack.

The main distributing frame equipment is mounted on the existing frame on the gunrod floor, and a 4-position test desk surmounted by a test jack cabinet has been installed in an adjacent position. Figure 4 shows the front view of the test desk, the test jack cabinet and a portion of the main distributing frame.

The switchboard, which is of the No. 1 common battery type, occupies two rooms on the fifth floor. It consists of:

158 Control positions, each equipped with 10 cord circuits

2 Delay positions, each equipped with 10 cord circuits

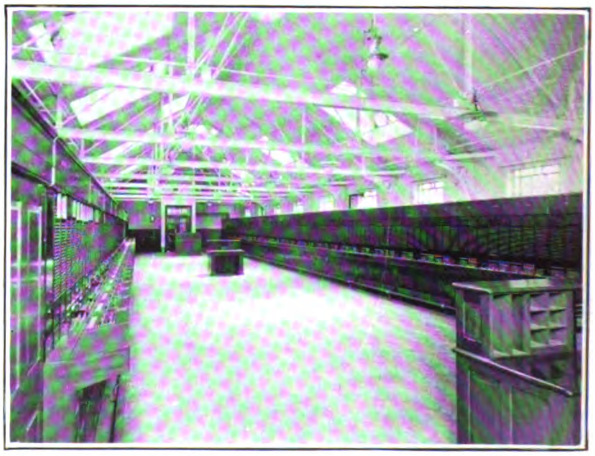


Figure 14—Operating Room—South Wing.

29 Through positions, each equipped with 17 cord circuits

11 Junction positions, each equipped with 30 plug-ended junctions

1 Service P.B.X. position, equipped with 17 cord circuits
1 Fault position

It is equipped for 1,580 calling equipments for jack-ended junctions (control positions), 870 calling equipments for jack-ended junctions (through positions), 330 plug-ended junctions and 2,800 outgoing junction multiple (6 panels per multiple).

The "transmission" includes a repeating coil associated with condensers and impedance coils and relays acting as impedance coils associated with a 30-volt battery. Diagrams of the "B" cord circuit, control cord circuit and universal cord circuit are shown in Figures 5, 6, and 7, respectively.

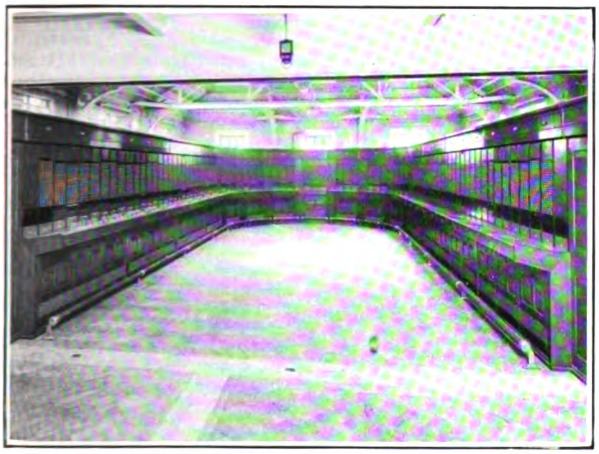


Figure 15—"Through" Positions in Horseshoe Bend.

The arrangement of the switchboard is shown in Figure 8, which also shows the positions of the desks and operator's meter cabinet. Sections numbered 1 to 62 are wired and equipped as control positions, including two delay positions. The front equipment of a typical section of this type is shown in Figure 9, whilst Figure 10 shows the rear view of a suite of control positions with rear doors removed. The answering jacks and lamps are ancillaried, giving primary and secondary appearances. For night working the circuits will be concentrated on sections 9 to 26, inclusive. Each position is furnished with a Veeder clock for call-timing purposes. Sections numbered 63 to 68 are designed as regular junction sections, No. 63 being unequipped at present, whilst positions 172 to 182, inclusive, in sections 64 to 68 have been equipped with 30 plug-ended junctions per position. Sections numbered 69 to 84 are arranged for "Through" positions, the front equipment of a typical section being shown in Figure 11. No provision is made for ancillary working on these positions. For night working the circuits will be concentrated on sections 81 to 84, inclusive.

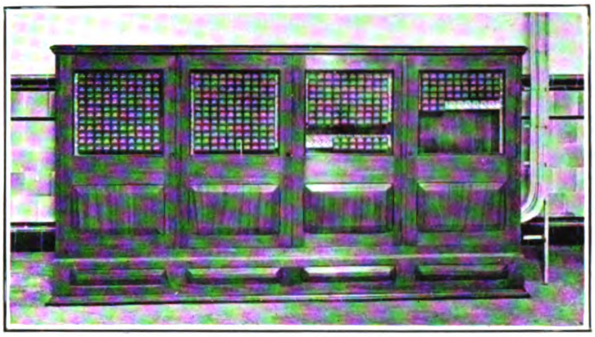


Figure 16—Operator's Meter Cabinet.

Section No. 84 provides a position equipped as service P. B. X. and another position equipped for fault service.

General views of the operating room taken from various aspects are shown in Figures 12, 13, 14 and 15. The 4-bay cabinet for operators' meters is seen in Figure 16. Figure 17 shows the 14-position monitors' desk equipped for information service; the commencement of the suite of control positions is seen in the background.

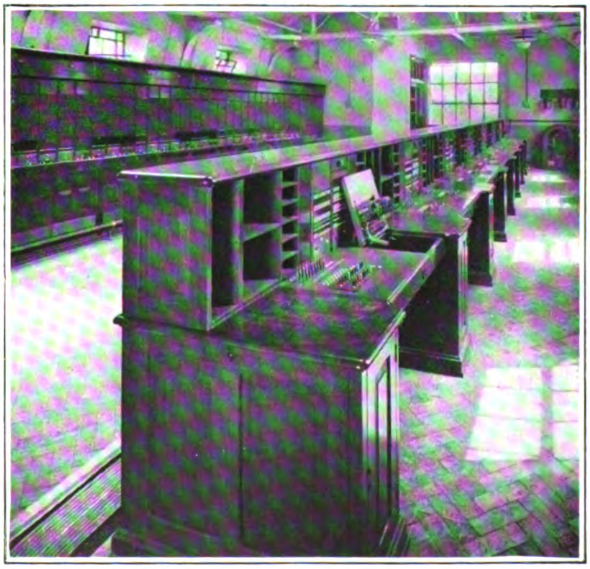


Figure 17—Information Desk, Toll Exchange G.P.O. South.

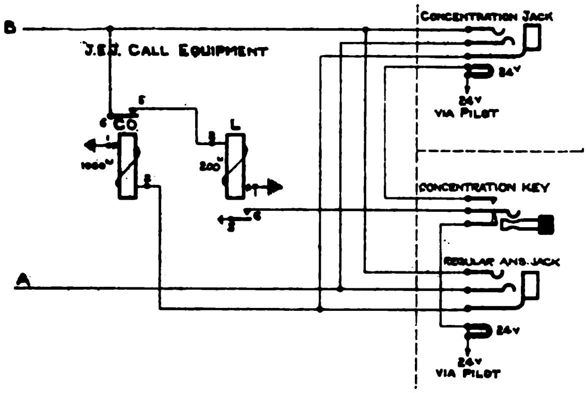


Figure 18—Incoming Jack-ended Junctions from Manual Exchanges—"Through" Positions.

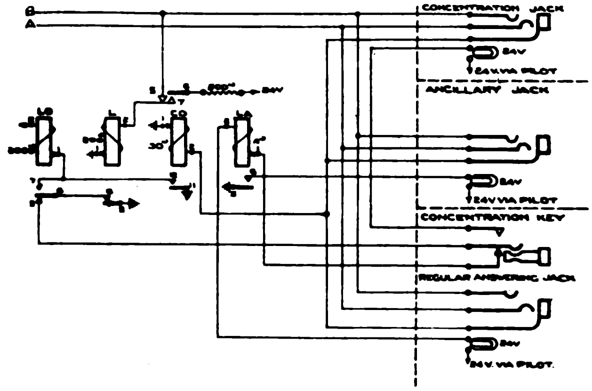


Figure 19—Incoming Jack-ended Junctions from Manual Exchanges.

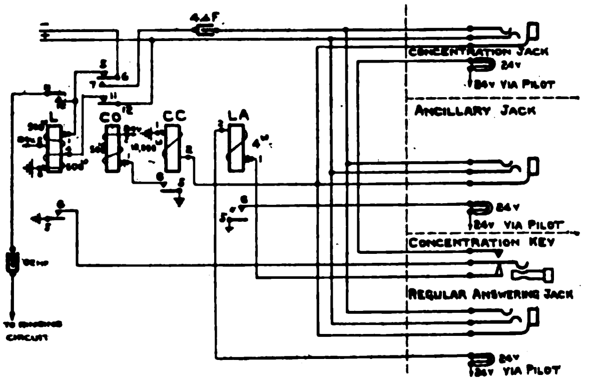


Figure 20—Incoming Jack-ended Junctions from Automatic Exchanges.

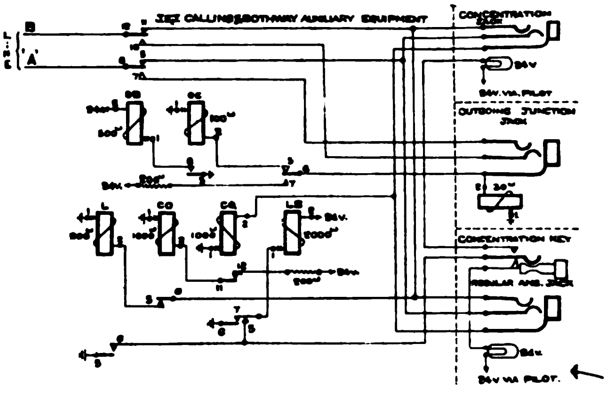


Figure 21—Bothway Jack-ended Junctions to and from Manual Exchanges.

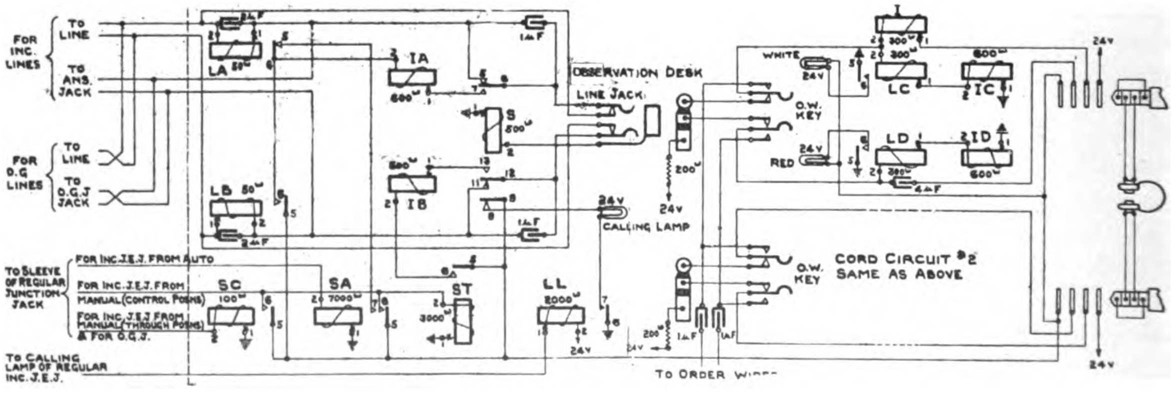

FOR INC. LINES
TO LINE
TO ANS. JACK
FOR O.G LINES
TO LINE
TO O.G.J. JACK
TO SLEEVE OF REGULAR JUNCTION JACK
FOR INC. J.E.J. FROM AUTO
FOR INC. J.E.J. FROM MANUAL (CONTROL POSNS)
FOR INC. J.E.J. FROM MANUAL (THROUGH POSNS) & FOR O.G.J.
TO CALLING LAMP OF REGULAR INC. J.E.J.
LA 50ω
LB 50ω
IA
600ω
S
500ω
IB
500ω
SC
100ω
SA
7000ω
ST
3000ω
LL
2000ω
1μF
OBSERVATION DESK
LINE JACK
24V
CALLING LAMP
200ω
WHITE
RED
O.W. KEY
LC
IC
LD
ID
300ω
600ω
4μF
CORD CIRCUIT #2 SAME AS ABOVE
TO ORDER WIRE
24V

Figure 22—Line and Cord Circuit—Observation Desk.

Cabling and Circuits

The cabling of the switchboard has been arranged to give any combination of cross-connection; the answering equipments, primary, secondary and concentration keys and all the relay equipments are wired direct to the intermediate distributing frame.

The relays provided in the exchange circuits are of the flat type; and the installation furnishes the first instance of a manual equipment provided by Standard Telephones and Cables, Ltd., where flat type relays exclusively are used.

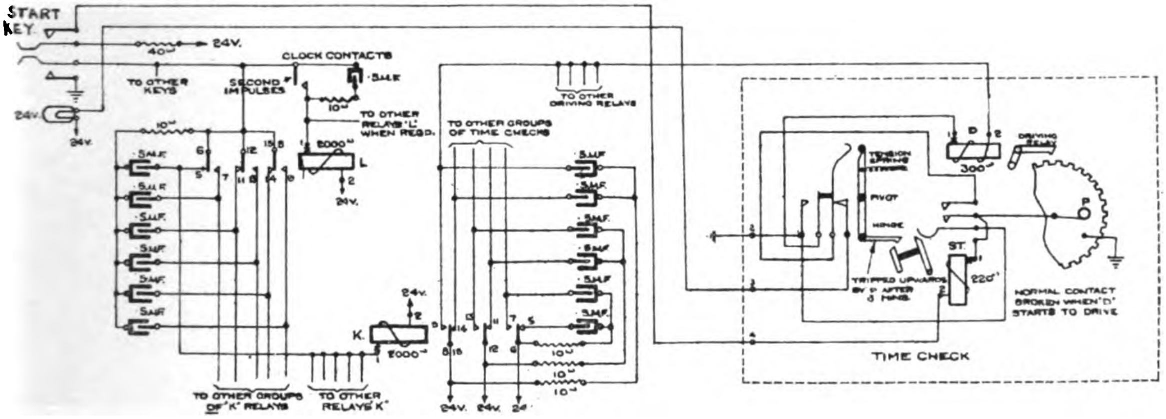


Figure 23—Time Check Circuit.

The provision of the "operator hold" facility from the cord circuits on those calls dialed out from automatic exchanges necessitated very sensitive relays in the cord circuits to ensure correct supervision, which has been secured by means of relays designed to operate on a low current.

Incoming junction circuits are shown in Figures 18, 19 and 20 and the bothway junction circuit in Figure 21.

The line and cord circuit for the observation desk is shown in Figure 22. It was redesigned to take care of the various new conditions encountered in this type of Toll operating.

An interesting departure from the general methods of timing the duration of telephone calls has been made in the case of the G. P. O. South equipment. Associated with each cord circuit on the control and delay positions is a Time Check, consisting of two relays of the Message Register type assembled as one unit, together with the associated timing mechanism. These Time Checks are mounted together on a rack in the apparatus room and are controlled at the switchboard by a key per cord circuit. The diagram of connections is given in Figure 23.

When the operator depresses the start key, the lower relay of the Time Check is energised, completing a holding circuit, breaking the lamp circuit, and making the circuit for the upper relay. The upper relay receives impulses at one-second intervals from the Master Clock to drive the mechanism. At the end .of three minutes (180th impulse) the hinge is tripped upwards, allowing the springs to return to normal, thereby breaking the circuit of the upper relay and completing the lamp circuit. On observing the lamp signal, the operator restores the start key to release the lower relay.

If a demand for extension of time is received the operator, after resetting, depresses the start key again and the Time Check passes through the same cycle of operation.

Acknowledgment

The author is indebted to the Traffic Section of the British Post Office for the traffic detail and map of the Toll area included in this article, and desires to take this opportunity of acknowledging the courtesy of the officers concerned. Thanks are due also to the Engineer-in-Chief of the British Post Office for permission to publish this article.

Pole Timber and Its Preservation

By C. A. SMITH

European Engineering Department, International Standard Electric Corporation

Introduction

When consideration is given to the quantities of timber being used each year for supporting the aerial line plants of the world, to the still greater quantities annually consumed for general purposes, and to the immense number of wood poles and cross arms already in place in the United States and in Europe, the question arises whether all this timber has been and is being provided with adequate protection against premature decay. In countries where plentiful supplies of pole timber are near at hand and where labour is cheap, the question of preservation is never seriously considered. In other countries, where suitable pole timber is scarce and where the cost of transport is high, methods have long been applied to extend the useful life of wood poles.

It was the birth and growth of the railway systems of England that first called for an effective method of preserving timber, particularly wood sleepers, from decay. The use of the heavy oils of tar, commonly called creosote, was first introduced for this purpose by John Bethell in 1838. The ever-growing demand for pole timber—apart from other kinds—with recurrent increase in prices, has become a matter of considerable concern to line plant engineers, particularly in view of the serious shortage of suitable stocks, notably in Europe and certain of the American States. The depletion of forest supplies from many parts of the world and the slowness of the process of reforestation are not, however, the only reasons for anxiety. The problem of decay and the economic question of the preservation of timber is equally a matter of concern.

In regard to economy, the factor of first importance to consumers is the physical life of wood poles and the resulting effect upon the annual charges of aerial plant and the charges to be made for the service rendered to the public. Any increase secured to the life of a wood pole due to preservative treatment, if obtained at less than the cost of replacing the equivalent untreated poles throughout the same period, is economical; or otherwise stated, let

T = Life of aerial line support using preserved wood poles

t = Ditto using unpreserved wood poles

If $(T - t)$, the extension of useful life arising from the employment of preserved poles, is obtained at less cost than that of replacing unpreserved poles during the time $(T - t)$, the system with preserved poles ought to be chosen. Preserved poles, moreover, are conducive to better service, because there are fewer chances of interruption incident to replacement than with plain wood poles.

Primitive man no doubt discovered that the stakes he pointed by fire lasted much longer than others, but he could not tell why charring should be effective. With the advance of time, and from necessity, man has progressed in knowledge of the causes of timber decay. Much has been achieved in delaying the inevitable consequences of neglect, and today the results of organised research are seen in the benefits derivable from practical methods of treatment.

Pole Timber

While cedar and chestnut are the most favoured woods in America for telephone poles, in Europe the timber preferred for this purpose is cut from the extensive fir and pine forests of Scandinavia and Russia, and the tree chosen by the British Post Office is the red fir of commerce known as *Pinus Sylvestris.* The red fir, together with other firs, the pines and the larches, which are the principal members of the conifer group and are distinguishable by their needle-shaped leaves, thrive best in cold or temperate climates. By the nature of their stately forest growth, they are tall and straight and particularly free from low branches (Figure 1).

The growth of these trees is comparatively rapid and their straight stems, during the vigorous period, often extend 2 to 3 feet in a season; but while, in favourable soils and situations, they reach maturity in from seventy to eighty years, those marked for telephone poles are cut at a much earlier period.

It is a generally accepted condition that timber shall be felled in winter when the sap is down, in order to facilitate seasoning and the subsequent process of preservative treatment. It is known also that the strength of timber is affected by its moisture content; and from a series of tests it appears that wood containing about 15 percent of moisture is at its maximum strength. For these reasons, felled timber must not be allowed to lie in wet locations before removal to the drying grounds.

Figure 1—At the Fringe of a Swedish Pine Forest.

The timber from northern Europe is floated down the rivers to the local ports, from whence it is collected and shipped in loads of about

6,000 or 7,000 poles. British consignments are landed at various coastal depots where the seasoning grounds and creosoting yards are located.

Wood poles have the immense advantage of great flexibility and, mechanically, are very suitable for the purpose of aerial line support, for the loads they are called upon to withstand are similar in character to those borne by the trunks of the original trees. A valuable feature of the fir or pine pole is its elasticity.

Since the mechanical properties of timber vary considerably, it is necessary in all calculations to employ a very conservative figure for its ultimate strength. The maximum fibre stress, as determined from "breaking tests" and referred to as the Modulus of Rupture, varies with different woods from 4,000 lbs. per sq. inch for the softest kinds, to about 18,000 lbs. per sq. inch for the hardest species. After extensive experiments many engineers have adopted the figure of 7,800 lbs. per sq. inch for red fir, creosoted.

The usual form of specification issued to the suppliers of pole timber states that every tree felled must contain the natural butt; i.e., the tree must be sawn off as close to the ground as possible. The timber must be sound, hard-grown, straight and free from knots, and the bark must be completely removed; also, the whole of the operations connected with delivery, preparation (storage seasoning) and creosoting of the pole timber, must be carried out under supervision.

It may be of interest to refer briefly to the manner in which poles are measured, and to explain the meaning of the terms "string" and "caliper" measures as applied to timber:

(*a*) String measure consists in girthing the pole at half length with string or tape. The content is given by:

$$\frac{L}{113}\left(\frac{g}{4}\right)^2 = \text{cubic feet}$$

(*b*) Caliper measure consists in taking the diameter of the pole at half length by means of a pair of calipers. The content is obtained from:

$$\frac{L \cdot d^2}{183} = \text{cubic feet}$$

L, is the length of the pole in feet; g, the girth; and d, the diameter measured in inches at half the length of the pole.

The weight of untreated fir or pine wood varies from 30 to 40 lbs. per cubic foot.

Reforestation

In the countries chiefly concerned with timber production, especially those where climate and soil conditions are best suited for the growth of soft woods, reforestation is now being vigorously pursued in order to maintain supplies after existing stocks are exhausted. During the winter of 1925 more than 39,000,000 new trees were planted in Great Britain as part of the programme begun by the Forest Commission about six years ago for restoring the forests of England, Scotland and Wales. The trees occupy a space of 22,000 acres of what would otherwise be chiefly waste land. Since it commenced work the Commission has planted 52,500 acres and has assisted local authorities to plant another 5,000 acres. These activities have resulted in the production of 184,000,000 new trees.

The programme, spread over ten years, provides for the planting of 250,000 acres with 450,000,000 trees, mostly of different varieties of fir and spruce, grown from seed in nurseries and then planted out. It is estimated that in twenty years from the first planting the enterprise will begin to show returns. At present Great Britain imports £50,000,000 worth of timber annually.

Characteristics of Wood

Wood consists of a complex system of minutely formed vessels or cells with fibrous walls which constitute the solid parts of the structure. With the exception of the sapwood—a comparatively soft layer near the surface and under the bark—the solid parts comprise the heart wood, at the centre of which are the crushed-up remains of what was once the pith. The function of the sapwood comprising similar tracheids or cells—the lungs of the plant—is to draw up by capillary action the water with dissolved salts from the roots. In the natural order of things—the cyclic changes of the seasons beginning with the rise of sap in springtime, the chemical changes induced later by the sun, and the diurnal absorption of air and moisture by the leaves—new cells are formed containing the protoplasm, the physical basis of life; and, by a process of coagulation, first a covering of cellulose and then of lignose or wood fibre is produced. Between the bark and the wood, therefore, a new layer is formed, called the cambium, which constitutes the season's growth. Hence the annual rings. In the conifer woods, these concentric rings are sharply defined and by counting them the age of the tree is determined.

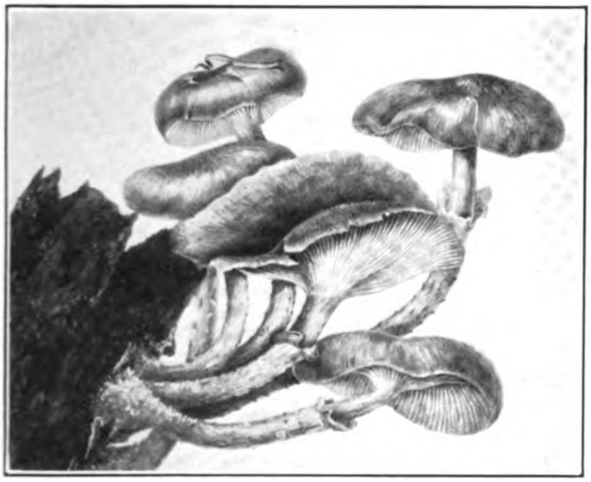


Figure 2—Fungoid Growth on Decaying Wood. (With acknowledgments to the Director of The Royal Botanic Gardens, Kew, Surrey, England.)

Decay of Timber

Decay, or dry rot, in timber is due to bacteria derived from various kinds of fungi (Figure 2) which feed upon the contents of the wood cells. The spores are blown about by the wind, and thus are brought into contact with the timber where, under favourable conditions, they penetrate into the cells and reduce the wood to a crumbling mass (Figure 3). For their growth, air, moisture and warmth are essential, and, as all three are usually present at, or just below, the ground level, it is there that wood poles are most susceptible to rot.

If air, moisture or warmth is absent, the bacteria or fungi cannot thrive, and decay is arrested. As an example of a case where air at proper temperature but no moisture is present, the coffins preserved from the times of the Pharaohs may be cited, while timber submerged in water at a suitable temperature but unexposed to air has defied decomposition for hundreds of years. Wood piles are excellent examples of the latter class. Again, wood exposed to water and air, but at very low temperature, is not liable to suffer from decomposition, a fact abundantly shown by the preservation of prehistoric canoes in ice-fields.

Another form of decay, not often met with in Europe but a serious menace in tropical countries, is due to termites; i.e., insects (Figure 4) that attack the pole, usually from the ground, where they penetrate and feed on the moist timber and quickly weaken it.

Felled Timber Preservation

For the destruction of fungi and the prevention of decay, it is necessary to poison the food supply of these parasites by injecting some kind of antiseptic. The coarse grain of the firs, pines and similar soft woods is very suitable for

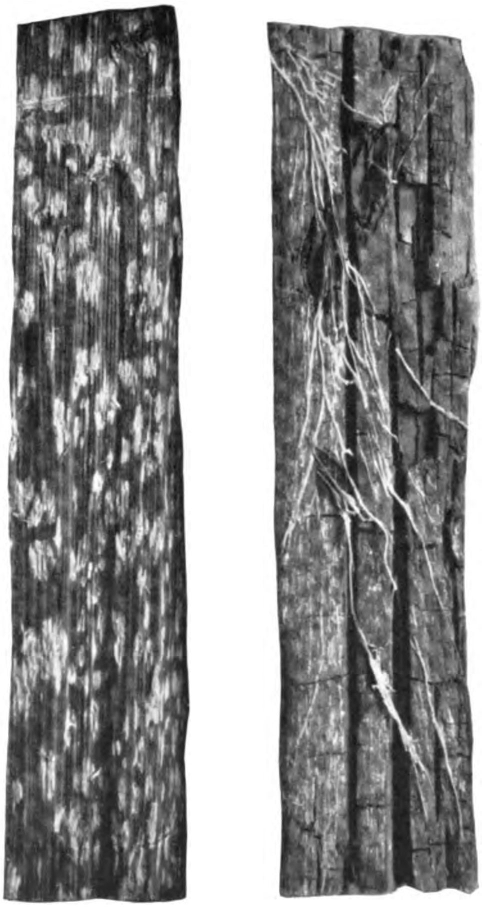


Figure 3—Two Progressive Stages of "Dry-rot." The thread-like filaments are known as mycelium.

this treatment. The antiseptic employed for the purpose may be a water solution applied cold or hot in a bath or by injection, or by the approved British method of injecting hot creosote oil.

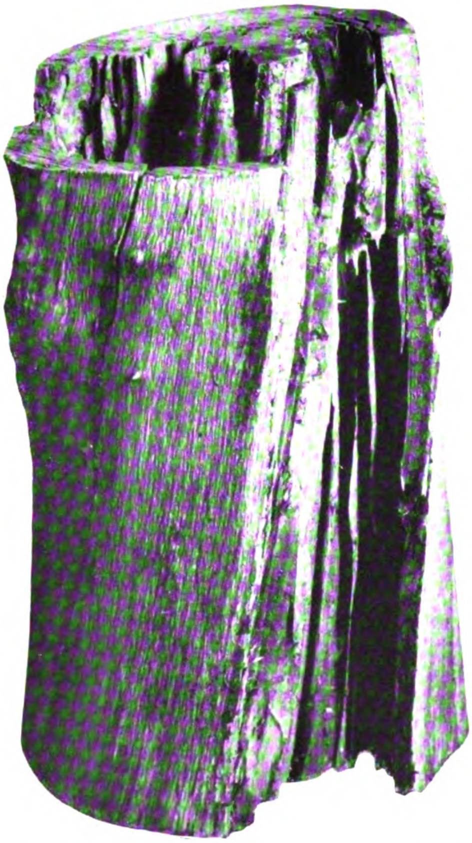


Figure 4—Piece of an Untreated Pole Butt Ravaged by Insects.

A preliminary to the application of any of the various methods of preserving timber is prolonged exposure to natural air-drying which sometimes, however, is followed or replaced by exposure to live steam, for the purpose of seasoning. Air-drying alone is considered to be the most satisfactory process of seasoning, provided that it is not hurried.

There have been introduced in the past many preservative processes, generally of watery solutions bearing names according to the salts employed, and often with extravagant claims of superiority. In practice, however, none of these processes have been proved effective in prolonging the life of the timber to the extent desired. In general, the great disadvantage of watery solutions is the tendency for them to wash out due to the effects of rain, notwithstanding ingenuous means devised for overcoming this defect.

Other objections to the use of these solutions are: (1) the difficulty of providing special plant which will resist the corrosive action of the liquids when the injection method is employed, (2) the corrosion of pole iron fittings, (3) danger to workmen, and (4) the poisoning of streams and of animals grazing on pasture lands, due to noxious chemicals draining out of standing poles which have been thus impregnated.

In view of these objections only the following very brief reference will be made to the best known of these processes:

Process	Chemicals Used
Kyan.................	Corrosive sublimate
Boucherie.............	Copper sulphate
Burnett...............	Zinc chloride
Ferrell................	Aluminium sulphate with sodium chloride and other salts
Hasselman............	Sulphates of copper, aluminium and iron, with kainite
Falk Novoling.........	Sodium fluoride and phenol

The "Aczol" process more recently introduced promises to rival the creosoting process if the advantages claimed for it are substantiated in practice. This process, invented by a Belgian chemist, utilises a solution of Ammonia-Copper-Zinc-Phenol, and is dark green in colour. It is applied cold, either in an open bath or, preferably, by the more effective method of pressure-injection. It has greater penetration than creosote. It is supplied and stored in iron drums.

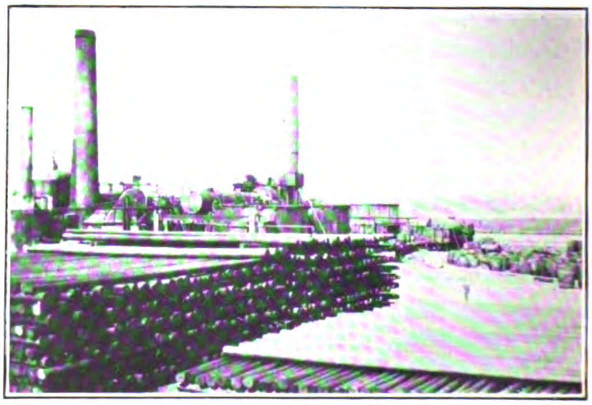


Figure 5—A Typical British Creosoting Plant.

Another process undergoing trial employs an aqueous solution of zinc and arsenic forced into the pores of the wood. The theory is that the zinc arsenite enters into solution with acids evolved by the fungus organisms and that the resulting compounds are destructive to the fungus. It is stated that the preservative will remain in the wood indefinitely and will not be leached out by the action of the weather.

Creosoting of Timber

Experience has taught that there is no better way of preserving timber than by the old established English method of pressure creosoting (Figure 5). The ever increasing demand for creosoted timber in England, on the Continent, and in America is the best proof of the value of the process.

Plant

Various modifications of the original Bethell Process have been in vogue during the past fifty years, but the type of pressure plant has mainly been the same (Figure 6). This plant consists essentially of the creosoting cylinder proper and a containing vessel mounted above it. Both of these cylinders are fitted with steam coils, and the lower cylinder is provided with a rail track which extends beyond the door on the trackage running from the stacks of timber in the creosoting yard. The upper and lower cylinders are connected together by means of large piping, so that the contents may be transferred quickly from one to the other. A water condenser is arranged in such a way that the lower cylinder may be connected to it and the whole kept under reduced pressure and at a temperature controlled by means of the steam coils in the cylinder itself. Creosote under pressure is supplied to either cylinder by means of a pressure pump, and compressed air or vacuum is supplied by another larger pressure pump. A control board is fitted with instruments which indicate steam pressure from the boiler, air pressure, vacuum, and creosote pressure within the creosoting cylinder. Recording thermometers are generally used, to give records of temperature during the whole cycle of operations. In practice it is convenient and advisable to have recording instruments for vacuum pressure as well as for temperature.

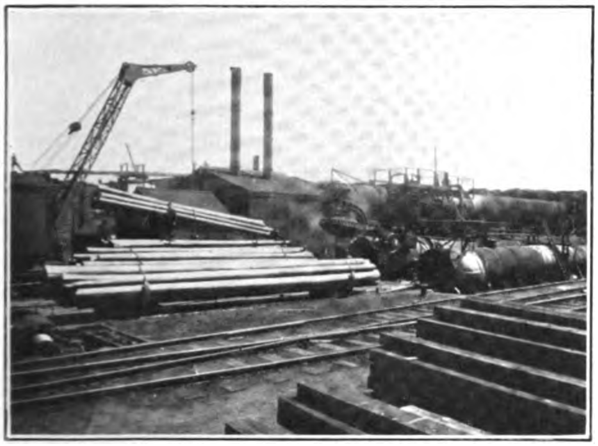


Figure 6—Creosoting Plant at Newport, Monmouthshire. (With acknowledgments to Messrs. Burt, Boulton and Haywood, Ltd., London.)

Impregnation

There are four main processes:

(*a*) *The Full Cell Process* (originally known as the Bethell Process), in which seasoned timber is fully impregnated with creosote by first exhausting air from the timber in the closed cylinder containing the timber, filling up the cylinder with hot creosote from the overhead container, forcing the creosote in by pressure until absorption is complete, and then emptying the cylinder and removing the timber fully charged with creosote.

(*b*) *The Boulton Process*, applicable specially to timbers for which no seasoning time is available. This consists in immersing the wet timber in a cylinder charged with hot creosote oil and applying vacuum. The oil must always be kept at a temperature above that at which water boils. The water vapour is condensed in the condenser placed between the creosoting cylinder and the vacuum pump. The temperature required is considerably below that at which injury occurs to the timber. Since the latter is always immersed in oil, there is no tendency to "shake."

As and when the water is removed, more oil is pumped in, and finally pressure is applied until the desired impregnation is reached. The cylinder is emptied and the charge removed.

(*c*) *The Rueping Process*, or that of full impregnation of sapwood and subsequent removal of oil. This process consists in first compressing air into the timber in a cylinder in which there is no oil. Above this cylinder, and suitably connected with it by pipes and valves, is a closed reservoir containing the oil. When the desired air pressure is reached, say four atmospheres, the oil is allowed to gravitate from the reservoir to the cylinder, whilst the compressed air takes its place in the reservoir. Pressure is then put on by force pumps until the desired quantity of oil has entered the timber. This pressure will be one or two atmospheres above normal air pressure. The pressure is then released, the oil removed from the cylinder, and vacuum applied. On first releasing the oil pressure, the compressed air imprisoned in the wood expands and expels a large quantity of the oil. The vacuum removes some more. Although the internal cells of the timber do not retain the full plugging of oil, they retain a coating of preservative. With this process it is possible to save at least 50 percent of the oil employed.

(*d*) *The Lowry Process*. The timber is placed in the creosoting cylinder, creosote is pumped in under pressure, and the pressure is maintained until the desired penetration has been effected. The oil is then pumped away and vacuum is applied to the cylinder until the excess creosote has been removed. This and analogous processes are largely used by the main railroads of the United States and Canada.

The custom of steaming wet or unseasoned timber before the admission of oil to the cylinder, formerly practised in Europe and very largely in America, has proved to be of no advantage in Europe. In America, the advisability of continuing its use is understood to be under investigation.

Perhaps the most interesting of the above mentioned processes is (*c*). It was introduced by Max Rueping of Charlottenburg in 1902, and is known as the "Empty Cell Method." The reasons for its adoption are:

(i) An economic reduction in the amount of creosote oil required.
(ii) The absorption of only so much liquid as is necessary to saturate the whole of that portion of the timber which can be permeated by the preserving liquid.
(iii) Oozing and sweating of wood is prevented and the timber, being dry and clean, it can be painted, if desired, after about three to six months standing.
(iv) Saving in cost without material reduction of the life of the poles so treated.

In practice there has been no occasion to replace certain poles which were impregnated by the Rueping Process in 1912.

In the Rueping Process it is customary to use seasoned timber as the general effect of this method is only apparent when the wood cells and pores are free from moisture. All kinds of combinations have been tried and it is quite possible that steam seasoning in conjunction with the Rueping Process may be utilised in some cases. If steam seasoning is used, vacuum must be applied after the steaming operation to assist vapourisation of the moisture in the timber.

The Rueping Process, as practised in England, begins with air pressure, as initial vacuum would not produce any beneficial result. The air pressure usually is raised to about 4 atmospheres above normal. The temperature of the creosote is from 150 to 180 degrees Fahrenheit. The creosote pressure may be anything from 80 to 200 lbs. per square inch according to the nature of the timber. After release and removal of the creosote from the cylinder, the final vacuum usually is drawn to about 26 inches. The oil remaining in the timber will vary according to the kind and condition of the wood at the time of treatment, and to the amount of oil put in under the maximum pressure. In the case of European poles of *Pinus Sylvestris*, it is customary to inject a maximum amount of oil—equal to about 12 lbs. per cubic foot—and to leave in the timber about 5 lbs. per cubic foot.

In all timber there is a possibility of some portion of the wood being drier or more seasoned than others. This condition is largely immaterial when the pole is creosoted by the Full Cell Process, but in the case of the Rueping method, unseasoned portions of wood may not be completely impregnated, since the initial air pressure prevents the release of moisture, and the interior cell walls in these parts do not therefore get their due proportion of oil.

In the case of the Lowry Process, which resembles the Rueping Process but which does not employ air pressure above normal, the return of oil from the timber is less than with the Rueping Process. With the older processes, the aim usually was to inject into the wood as much oil as possible and for that reason the oil was let into the cylinder under a vacuum. The Boulton Process, which falls into this category, provides a means of removing the moisture from damp timber without prolonged stacking. If applied to the limit, as much as 20 to 30 lbs. of oil per cubic foot can be left in the timber.

With the Rueping Process there is not the same quantity of creosote left in the timber as with the Full Cell treatment, and as all timber "cracks" when exposed, the empty cells become exposed and are then subject to decay. With a fully creosoted pole there is not the same probability of "cracking," as all cells are filled. Moreover, the flow of creosote down the pole tends to fill in cells which may be exposed, due to "cracks." It also saturates the surrounding soil, checks decay at the ground line, and thus aids in lengthening the life of the pole.

In summarising in general terms the various available methods of creosoting pole timber, it may be stated that the Empty Cell Process has the advantage that the quantity of creosote consumed is a minimum, also that poles so impregnated may be painted after a short standing period and Ruepingised poles do not ooze or sweat so as to cause damage to property or clothing. The Full Cell Process, on the other hand, affords the greatest assurance of maximum length of life of the poles.

Thermionic Vacuum Tubes

By L. H. BEDFORD

Engineering Department, Standard Telephones and Cables, Ltd.

and W. T. GIBSON

European Engineering Department, International Standard Electric Corporation

THE thermionic vacuum tube now has a sufficient diversity of uses in communication engineering to justify a description of the various types available as well as of the methods employed in its manufacture.

The history of the vacuum tube as an instrument of value to the communication engineer dates from Professor J. A. Fleming's production in 1905 of the two-electrode "valve" which consisted of a filament and an anode mounted in a vacuum. When heated, the filament emitted electrons which could be collected by the anode. This tube was of use only as a rectifier. The next great step was made in 1907 by de Forest, who introduced a third electrode between the filament and the anode for controlling the anode current. It undoubtedly was the precursor of the modern vacuum tube, but development was very slow in the early years, largely because of the difficulty experienced in procuring and maintaining a suitably high vacuum. The development of the modern high vacuum tube dates from 1912. At this time the American Telephone and Telegraph Company, and the Western Electric Company were carrying out research work on telephone repeaters and had recognised that the vacuum tube amplifier would become a very valuable instrument provided it could be made stable in action, and with long life.

High vacuum technique had been developed to a high point as a laboratory art by Professor Dewar and numerous others. Although these methods were not being practised in ordinary glass-working establishments, as soon as the necessity for obtaining and maintaining an exceptionally high vacuum was thoroughly appreciated, they were adapted to factory procedure and a high vacuum product became quickly available.

Having obtained the high vacuum by methods which will be described at more length in what follows, attention was turned to the development of a suitable source of electrons.

The filament desired is required to meet two conditions: (*a*) long life and (*b*) high thermionic efficiency, that is, high electron emission per watt of heating power. These requirements, however, are invariably conflicting, for the relation between emission and temperature is such that increase of temperature gives increased thermionic efficiency, while at the same time the rate of evaporation of the emitting material is increased, with consequent reduction of life. Compromise, therefore, is necessary.

The actual relation between emission and temperature is given by Richardson's equation:

$$i = AT^{1/2}e^{-b/T},$$

where i is the electron emission current,

T is the absolute temperature,

A and b are constants.

In studying the economy of operation of filaments, it is generally of greater importance, however, to consider the relation between i and the power w expended in maintaining the filament at temperature T. C. J. Davisson, of the Bell Telephone Laboratories, Inc., has devised a system of coordinates such that when w and i are plotted as abscissæ and ordinates, the power emission curve for the surface appears as a straight line on the chart, provided, however, that the material obeys the Richardson equation and that the power radiated is proportional to the fourth power of the temperature in accordance with the Stefan Boltzmann law. By means of this chart, the study of filaments is facilitated very considerably.

Among the chief materials available for filaments at the time the investigation was started were tantalum and tungsten. The constants, A and b, of these materials are such that unless the filaments are run at exceedingly high temperatures the emission is negligible. The efficiency is low and for tungsten at ordinary operating temperature, for example, may be of the order of 5 milliamperes per watt of heating power. At lower temperatures the efficiency is too low to be of any interest in the production of vacuum tubes for use in communication engineering. Moreover, at the temperature at which emission begins to be of useful magnitude the material is not very far below its melting point and the vapour pressure is so high that evaporation proceeds fairly rapidly with the result that the filament life is short. In the case of tantalum, similar statements apply. Furthermore, previous to failure by burning out, there is nothing to indicate that the end is near, inasmuch as the whole filament is so bright that any local temperature inequality cannot be discerned. The possibility of tube failure without warning is in itself a very serious disadvantage in a communication line, and alone practically rules out the use of these metals except for power tubes employing high anode voltages.

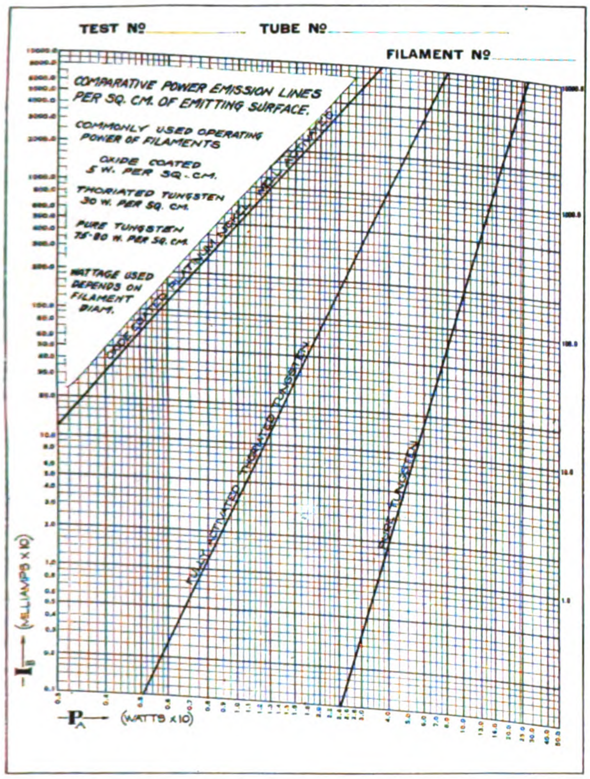


Figure 1—Power-Emission Lines for Tungsten, Thoriated Tungsten and Oxide Coated Filaments.

In 1905, Wehnelt had described a cathode commonly known as the "lime cathode," which was a very efficient electron emitter at relatively low temperatures. It consisted of a strip of platinum on which was placed a speck of lime. It had comparatively high efficiency and operated at a very low temperature, so that the vapour pressure was low, and the life might be made long. In addition, the temperature was so low that any local brightness variation preceding failure was easily visible. The life of the filament was, however, short on account of the coating material breaking loose from the metallic core, and falling off. The Western Electric engineers recognised that this filament had the properties they were looking for except that the life was too short and uncertain, and they concentrated their efforts on improving it. The results of the work led to the production of a very active coated filament of uniform

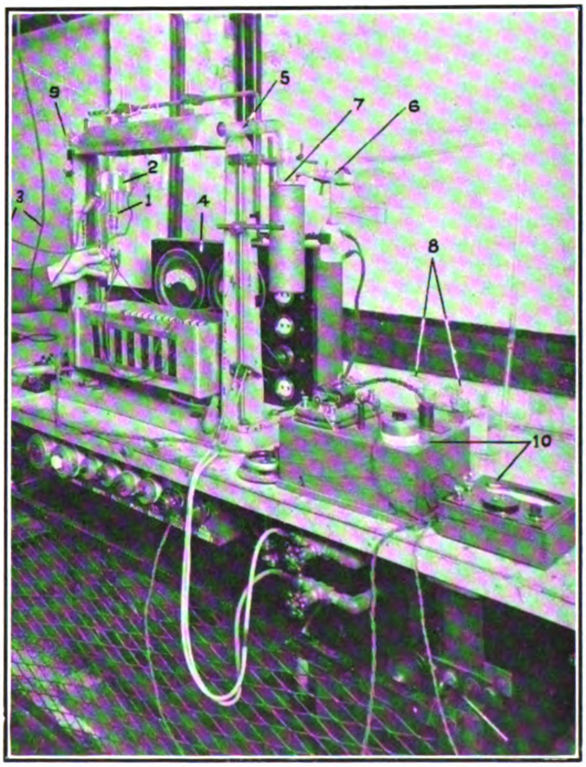


Figure 2—A No. 4211-D Tube under High Frequency "Gettering"; the last stage in the exhaust process. (1) 4211-D tube; (2) High Frequency Coil; (3) High Frequency Leads; (4) Bombarding Panel; (5) Header; (6) Mercury Aspirator; (7) Liquid Air Trap; (8) Mercury-sealed Cocks to Oil Pump System; (9) Ionisation Manometer Tube; (10) Ionisation Manometer Set (Hendon Valve Laboratory).

activity throughout its length, operating at a dull red heat, and having exceedingly long life so that it is now possible to make filaments having an efficiency roughly of 200 milliamperes per watt, and having a life of 25,000 to 50,000 hours or more. Furthermore, this type of filament, before burning out, gives considerable warning of failure, by the formation of bright spots upon it, so that it can be removed at leisure with no danger of interruption of service. It is also comparatively free from objectionable rustling noises which are heard in circuits of high amplification when tungsten filament tubes are used.

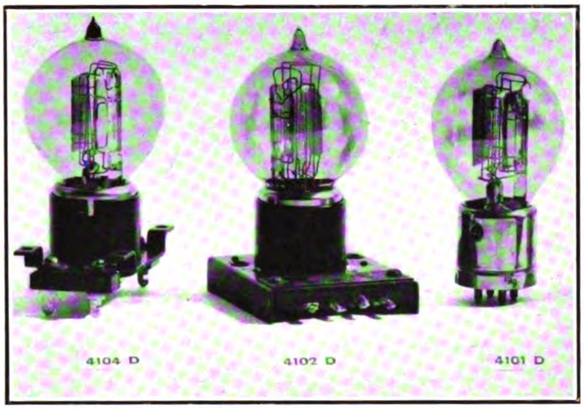


Figure 3—The Repeater Group.

Figure 1 shows comparative power-emission lines on the Davisson Chart for oxide coated as well as for tungsten filaments. A line for thoriated tungsten, another extensively used dull emitting filament, also is shown.

The method of manufacture of the modern oxide coated filament is essentially as follows: a wire or ribbon core of an alloy of platinum and nickel with a very low vapour pressure at the operating temperature is used. It is coated by applying a large number of thin layers of a compound of barium and strontium. After the application of each layer, the filament is heated in air to a high temperature to cause chemical combination of the materials with the core, and at the conclusion of the coating process the material is baked for some time to ensure its adhering firmly and not falling off while the tube is in service.

During the process of heating each layer, the compounds decompose first into barium and strontium oxides which then combine with the core-metals and oxygen, forming stable compounds. In this state the filament may be stored for future use. During the evacuation of the tube the filament is heated, and a reverse action occurs; oxygen is evolved and barium and strontium oxides are left very finely divided upon the surface.

The original filament was made in a similar way but had a core of platinum. The use of the alloy led to a very considerable increase in activity and life, and made possible a reduction in operating filament current. Continual development of details of technique of manufacture has led to increased activity and life, and at the same time has ensured a more robust product, so that the modern material can give high emissions and can be used with high anode voltages.

The processes involved in manufacturing this type of vacuum tube have been the subject of considerable investigation by Western Electric and International Standard Electric engineers, with the result that the details are now well understood, and the essential factors are kept under constant control in the factory. This supervision applies not only to all stages of manufacture, but also to the inspection and testing of all raw materials.

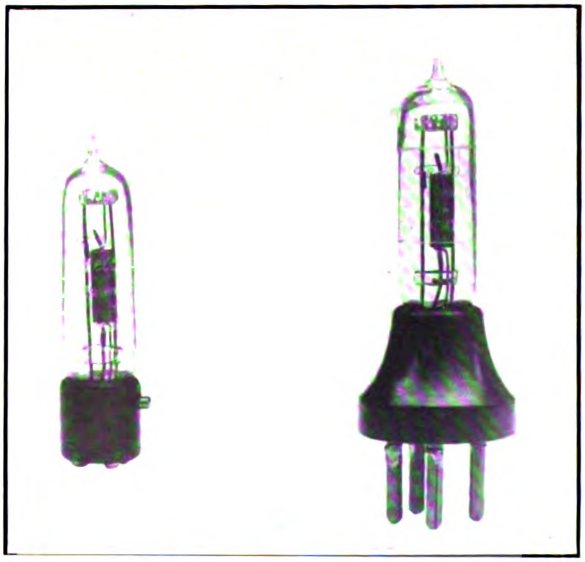


Figure 4—The Peanut Types G.125 and G.125-A.

In the manufacture of telephone repeater tubes, radio receiving and low power transmitting tubes, the same general methods of manufacture are followed. A point of the greatest importance throughout is absolute cleanliness—chemical cleanliness. All glass, for instance, must be cleaned specially and all metal that is to be located in a vacuum must be cleaned and denuded of gas before use by heating to very high temperature in a vacuum electric furnace.

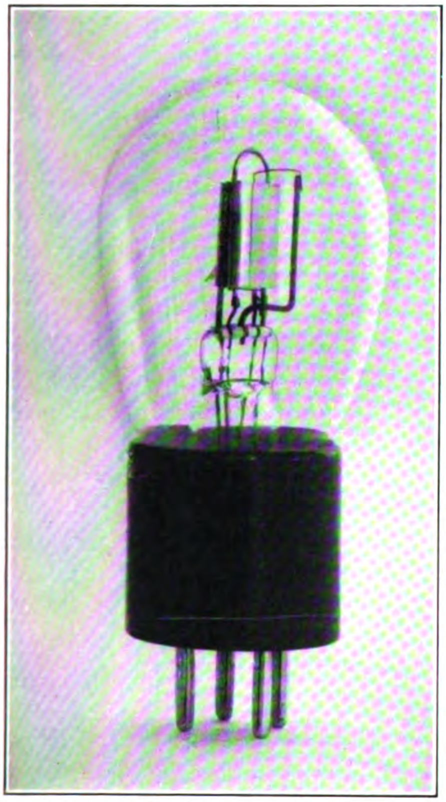


Figure 5—The G.225 Tube. (Magnesium Getter omitted for clearness.)

The parts are assembled by skilled workers, or by machines, and are located accurately in the required positions by electro-welding while they are held in jigs. The metal parts when correctly aligned and mounted upon their glass supports are sealed into the glass bulb, usually by machine, and the bulb is provided with a tube through which it may be exhausted. This tube in the case of the "tipless type" of vacuum tube, is sealed into the same end of the bulb as the supporting stem and is hidden in the finished product by being covered by the base.

The bulb is sealed by fusion on to the glass header of an exhaust station. A typical exhaust station layout is shown in Figure 2. Under the bench are located the necessary rotary oil pumps for producing a "fore" vacuum in the bulb of the Mercury Aspirator (6), the pressure here being of the order of 0.001 mm. of mercury. The Aspirator produces a high vacuum in the header (5) by entraining the gas molecules in a high speed mercury vapour stream flowing from the nozzle to the condensation bulb. To prevent mercury vapour diffusing back into the header, a liquid air trap (7) is provided. The bulbs to be exhausted are so placed that an electric oven can be closed round them, and connections made

TABLE

Group	Code No.	Filament Volts	Filament Amperes	Plate Volts	Amplification Factor	Impedance Ohms	Output as Oscillator
Repeater Valves.......	4101-D	4.4	0.97	130	5.9	6000	—
	4102-D	2.0	0.97	130	30	60000	—
	4104-D	4.4	0.97	130	2.4	2000	1.5 watts
Radio Receiving Valves.	G-125	1.0	0.25	45 to 60	6.0	25000	—
	H-125	1.0	0.25	45 to 90	11.4	45000	—
	G-225	2.0	0.25	120	8.5	17000	—
	P-425	4.0	0.25	130	6.6	6000	—
	P-612	6.0	0.12	130	6.0	6000	—
Radio Transmitting Valves (Radiation Cooled)............	4205-D	4.4	1.6	250 to 350	7.0	3500	5 watts
	ES 755-1	8.0	1.6	500 to 750	8.5	3200	20 watts
	4211-D	10.0	3.0	750 to 1000	12.0	3000	50 watts
	4212-D	14.0	6.0	1500	16.0	2000	250 watts
Water-cooled Valves....	4228-A	22	41	4000	16	—	4 KW.
	4220-B	22	41	10000	40	—	10 KW.
	SS-1916-1	22	41	17000	40	—	20 KW.
	4222-A	22	41	—	—	—	—

Notes: (1) The plate voltages listed in this Table are normal or normal to maximum.
(2) Figures given for the water-cooled valves are subject to considerable modification according to the condition of use.

to the electrodes at the same time. The exhausting schedule is in general similar for all tubes employing these oxide coated filaments. The glass is first heated, with vacuum pumps working, to just below its softening temperature, to denude it of gas. The filament then is subjected to a "breaking down" process in which the compounds of coating and core-metal are decomposed by heat. This step is followed by processes of filament activation, by means of which the thermionic efficiency is increased to the desired value, and by very intensive electronic bombardment of grid and anode. By making the grid and anode positive and drawing emission current to them from the filament, sufficient power is dissipated in these elements to raise them to a very bright red heat, which causes rapid evolution of gas. By this process the parts are raised to a much higher temperature than they will attain in service, and are held there until the gas is thoroughly pumped out. When the parts afterwards reach normal temperature, the pressure falls to an exceedingly low value.

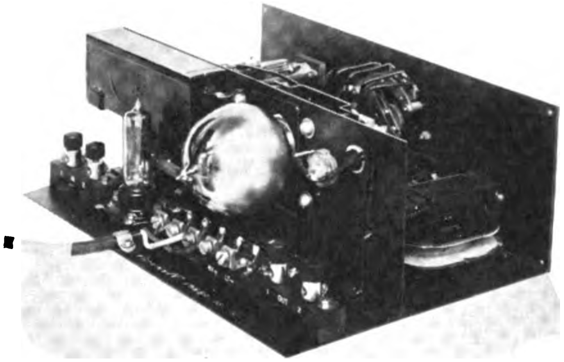


Figure 6A—The P.425-A Tube, shown in center of Kone Amplifier for which it was primarily developed.

In some types of tubes, a "getter" or small disc of magnesium metal is used. It may be vapourised and deposited as a silvery mirror on the glass of the bulb through the agency of heat conducted and radiated to it by the anode, which is heated by electronic bombardment. This process is useful in obtaining the final stage of high vacuum, inasmuch as gas is picked up by the magnesium in its passage to the walls of the bulb and is held there firmly by physical and chemical forces.

When the exhaust process has been carried to the desired degree, and the required filament efficiency is obtained, the bulb is sealed from the pumping equipment by carefully heating the constricted tubing and allowing the glass walls to fall in until they unite. In this process it is most essential that the heating be carried out in a manner such that gas is not liberated from the hot glass into the bulb.

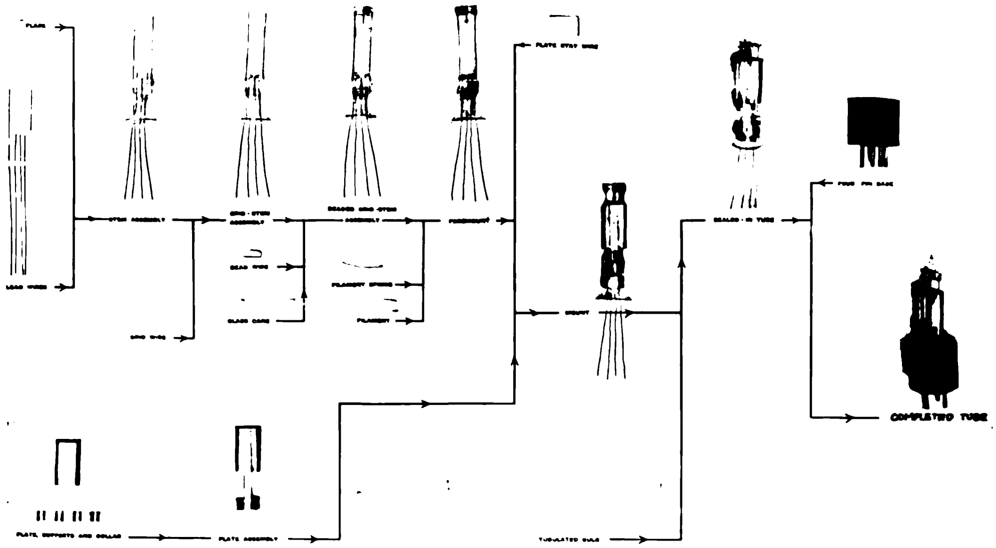


Figure 6B—A Development View of the P.425 Tube (with magnesium omitted).

After the tubes are removed from the pumps they are put through an "aging" process with a view to stabilising the thermionic efficiency of the filament, and they then are subjected to very searching tests framed to ensure the qualities desired for communication purposes.

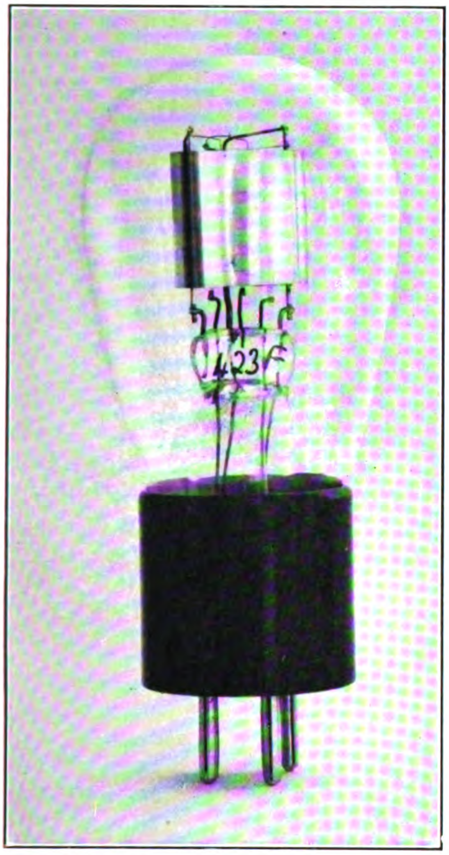


Figure 7—The P.612 Tube. (Magnesium getter omitted for clearness.)

Repeater tubes are placed in a test circuit which measures directly the power amplification or gain which they will give in a typical repeater circuit. The gain is measured not only at the normal filament current, but also at a current about 10 per cent below normal. The latter shows the working of the filament at "temperature saturation," a very important factor in the easy maintenance of long repeatered circuits. Measurements of plate impedance, insulation resistance and gas pressure also are made.

The foregoing, in general, is the manufacturing procedure in the case of all vacuum tubes employing the oxide coated filament.

Tubes manufactured by Standard Telephones and Cables, Ltd., may be divided into different groups according to their uses, as follows:

(1) *The Repeater Group.*—(See Table and Figure 3.) This group consists of the 4101-D, 4102-D and 4104-D vacuum tubes. These are all of similar appearance but have electrical characteristics suiting them to different uses in the telephone plant. Thus the 4102-D is of rather high impedance with high μ, and is used largely for the first stage; i.e., the voltage amplifier stage of 4-wire repeaters. The 4101-D is of medium impedance, and medium μ and is used in 2-wire repeaters and in the output stage of 4-wire repeaters. The 4104-D is of low impedance and low μ and is used in certain transmission measuring apparatus and in carrier telephony.

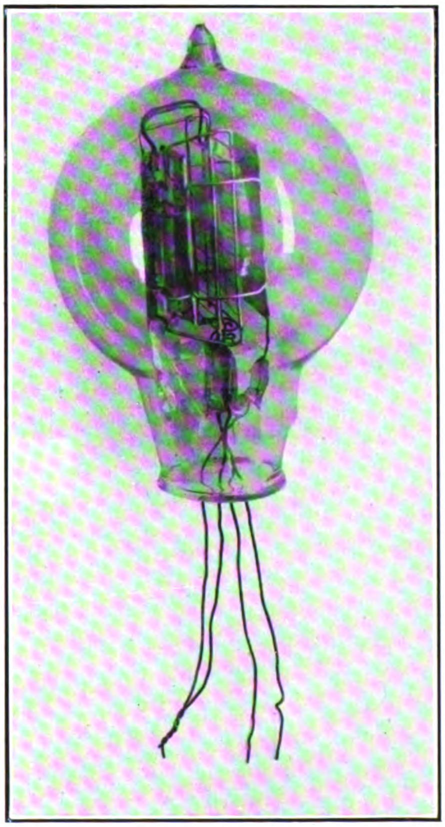


Figure 8—An Unbased 4205-D Tube, showing the long insulation path provided for the platinum lead. In other respects, the structure is identical with that of the repeater group of tubes.

(2) *The Radio Receiving Group.*—(See Table and Figures 4 to 7 inclusive.) This group consists of a series of tubes having lower filament

consumption, and characteristics suited to the different stages in radio receivers. They are the G-125, H-125, G-225, P-425 and P-612.

The nomenclature used in this group indicates to some extent the type of tube; viz.,

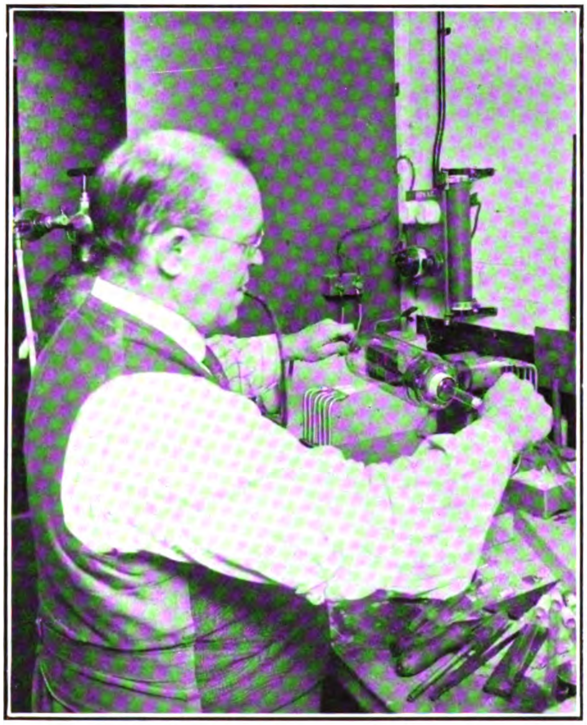


Figure 9—A 4212-D Tube in the Sealing-in Process. (Hendon Valve Laboratory.)

G—General purposes,
H—High frequency amplifier,
P—Power amplifier.

The three figures following the letter indicate the filament consumption, the first one giving the filament voltage and the succeeding two the filament current in hundredths of an ampere. Thus the P-612 is a power amplifier tube suitable for the last audio frequency stage. It operates with a filament voltage of 6, and with a filament current of 0.12 ampere.

With the exception of the 1-volt tubes the other members of the group are designed for direct operation from the accumulator supply without the use of rheostats. Such an operating arrangement is made practicable economically by the latest oxide coated filament and requires that emission be adequate until the accumulator is effectively discharged, and that the filament be not overloaded by a newly charged battery.

(3) *The Radio Transmitting Group.*—(See Table and Figures 2, 8, 9, 10 and 11.) This group may be subdivided according to the power rating of the tubes:

	Code Number
5 watt	4205-D
20 watt	ES-755-1
50 watt	4211-D
250 watt	4212-D

In order to reduce the operating temperature of the anodes or plates of the 50 and 250 watt tubes, they are made of black oxidised nickel, as this surface has a much higher thermal emissivity than bright metal.

(4) *The Water-cooled Group.*—An entirely different group of tubes in which oxide coated filament cannot be used is that distinguished as the "water-cooled" group (see Figures 12 and 13) and is used where large quantities of energy are handled, such as in the case of the Rugby Station.[1] It includes:

4-KW. tube—Type 4228-A
10-KW. tube—Type 4220-B

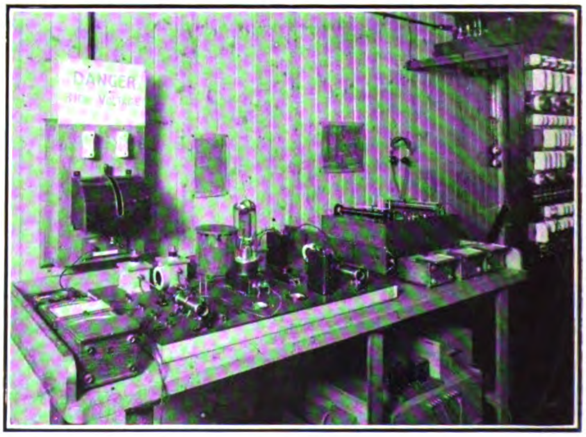


Figure 10—A 4212-D Tube on the Oscillation Test. The circuit is of the Colpitts type and is used for testing both 4212-D and 4211-D type tubes, and also for supplying the high frequency current for the gettering process (Figure 2). In the background is a receiving tube test set.

and the special 20-KW. high voltage tube SS-1916-1. Suitable rectifiers are provided to supply anode voltage to these amplifiers.

The important difference between these tubes and those previously discussed is that the anode forms part of the external wall of the tube. As the anode is of copper, which may be water-cooled, the greatest problem of high power tube design—that of getting rid of the power dissipated in the anode—is easily overcome. This design was made possible through the invention by Houskeeper, of the Bell Telephone Laboratories, Inc., of a means of making vacuum tight seals between metals and glasses having different temperature coefficients of expansion. The sealing process is accomplished by reducing the edge of the metal tube to a fine taper and at the same time making it very thin. The result, if the reduction is correctly made, is that the metal will yield to the expansion and contraction of the glass, and the joint will withstand temperature changes without any danger of cracking. Using this method, the 10-KW. anode is made of drawn copper, two inches in diameter, sealed directly at its open end to a glass envelope which serves to support and insulate the grid and filament assemblies, which are mounted within the anode. The grid and filament structures are designed specially to allow heating to very high temperatures during exhaust, and consequently are constructed of molybdenum, while the filament itself is of tungsten.

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[1] "Transatlantic Radio Telephony-Radio Station of the British Post Office at Rugby," E. M. Deloraine, ELECTRICAL COMMUNICATION, Vol. 5, No. 1, July, 1926.

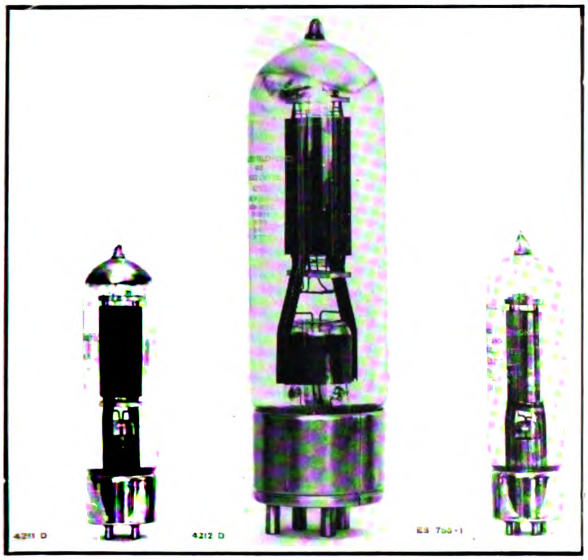


Figure 11—The 4211-D, 4212-D and ES-755-1 Tubes.

Just below the thin taper, which is sealed to the glass, a rim is provided all round the anode. When the tube is in use, this rim is clamped by means of a ring to a seat provided in the top of a metal water jacket. Electrical connection to the anode is made by connections to the water jacket. In the general method of use, the anode is at a high positive potential, say 10,000 volts, and water is supplied from a tank at earth potential through a rubber hose. By suitably choosing the hose dimensions, the conductance of the water column can be arranged to introduce negligible electrical loss.

These tubes are provided with pure tungsten filaments and necessarily consume considerable power in the filament, which contains sufficient material to ensure adequate electronic emission for very high peak values.

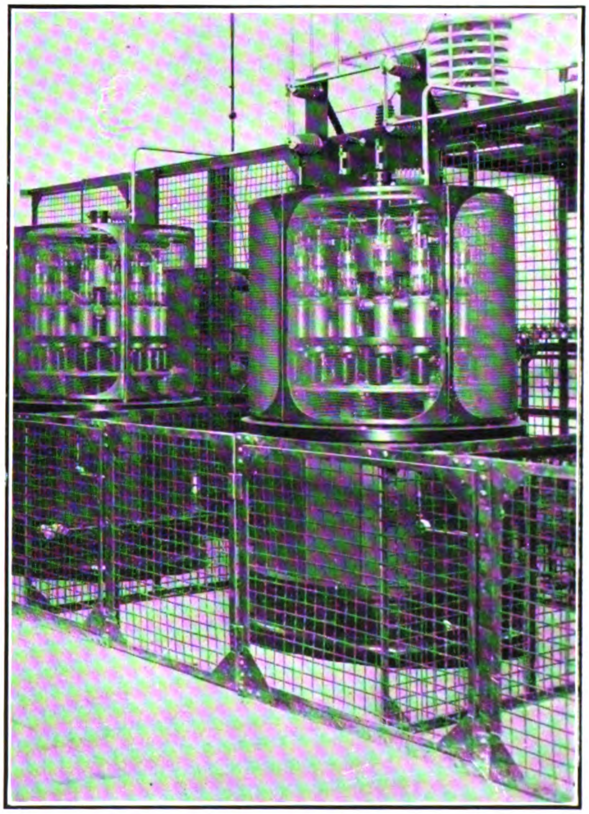


Figure 12— 4220-B Tubes in the Rugby Transatlantic Telephony Equipment.

Ordinary lead glass tubes have been designed to operate up to 12,000 volts. The special type SS-1916-1, 20-KW. tube, however, contains a

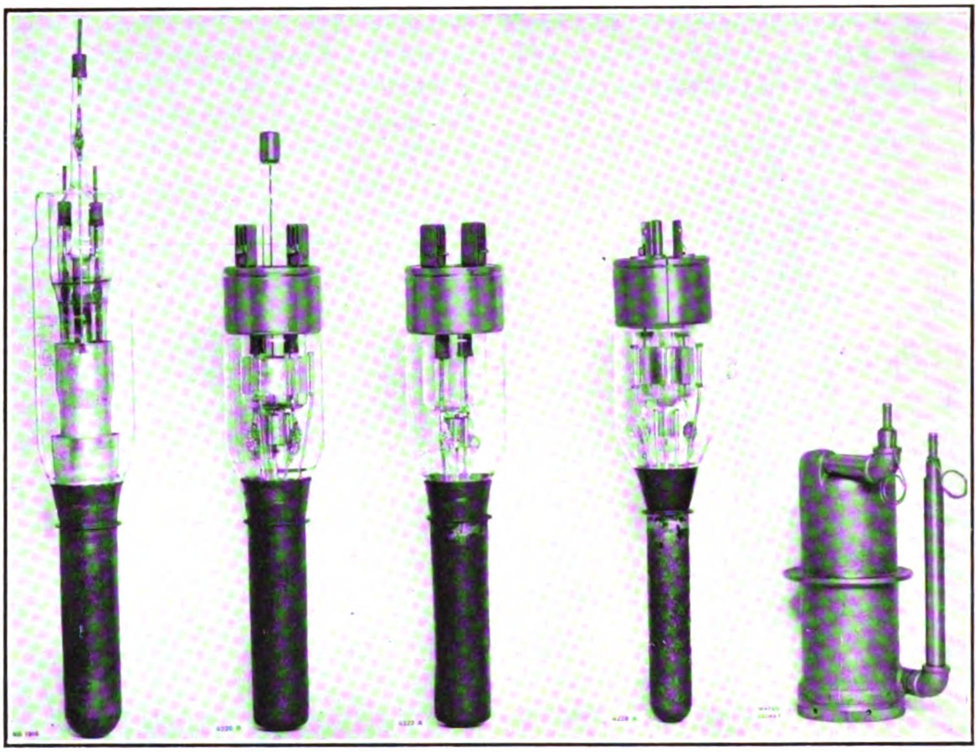


Figure 13—The Water-cooled Group.

Pyrex glass construction which makes possible the use of much higher voltages. This type can be operated with rectifier supply for the anode voltage at 17,000 volts.

The Gamewell Fire Alarm System

By L. H. WEBB

Engineering Department, Standard Telephones and Cables, Ltd.

THE development of the modern Fire Alarm System has paralleled and kept pace with that of large urban areas. With the growth of a town, property value and density of population increase very rapidly. It becomes vitally necessary, under such circumstances, to provide means of summoning the Fire Brigade immediately an outbreak of fire is discovered.

Experience has shown that prompt attention at the commencement of an outbreak is an important element in limiting the area affected and the loss sustained, whereas even short delays at this period may permit a fire to get a firm hold with consequent loss of life and property. The alarm equipment, therefore, must give immediate indication of the locality in which the fire has occurred and the indication must be fully automatic. Furthermore, a high degree of skill or intelligence in sending in the alarm signal or in reading the alarm indication at the Fire Station must not be necessary.

The design of the equipment, in addition, must be such that it can remain idle for months without risk of failure when required and give instant indication of any derangement which would prevent the correct transmission of the signal.

Modern Fire Alarm Systems usually employ telegraphic code signals and fall into two main classes.

1. Open circuit systems
2. Closed circuit systems

In open circuit systems the signal is sent by closing an electrical circuit and permitting the current to flow through the signaling apparatus. Such a system suffers from the very serious disadvantage that no indication is given when the circuit is disconnected by a fault, and the alarm box may be inoperative without any indication of the fact being given.

In closed circuit systems the current flows continuously, the alarm boxes being connected in series, and the signal is given by the opening of the electrical circuit. Should a disconnection occur it is, therefore, immediately indicated by the signaling apparatus at the Fire Station. This is known as the self-testing feature, and provides continuous supervision of the entire system.

The Gamewell Fire Alarm System

The Gamewell Fire Alarm System was one of the earliest practical systems and is based upon the closed circuit principle. The general arrangement of the System may be described as follows:

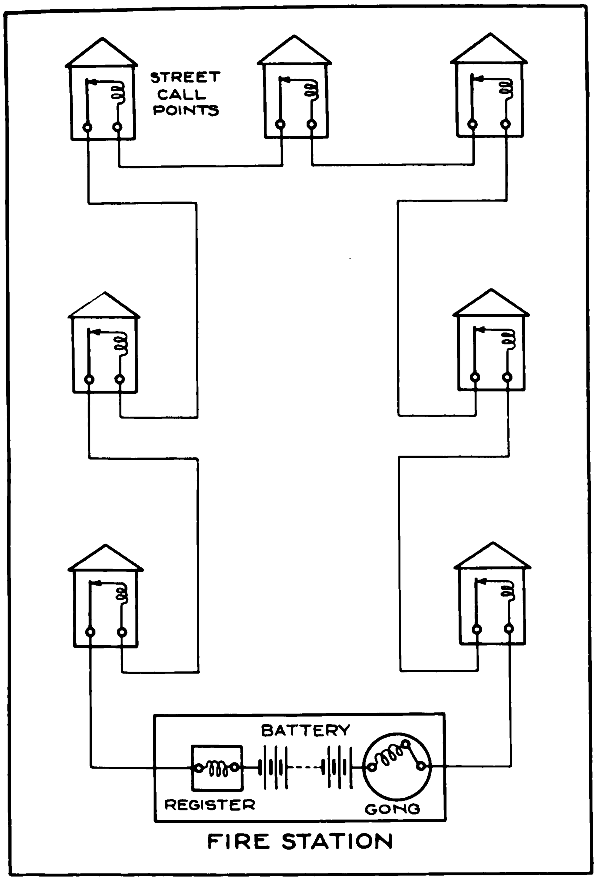


Figure 1—Gamewell Closed-circuit Loop, illustrating connections of street boxes and station apparatus.

The street boxes, as illustrated in Figure 1, are arranged at intervals on a single wire electrical circuit in series with the Fire Station signaling apparatus and a central battery located at the Fire Station. A continuous current of 100 milliamperes is maintained in this circuit, and any interruption thereof causes the Fire Station apparatus to operate immediately.

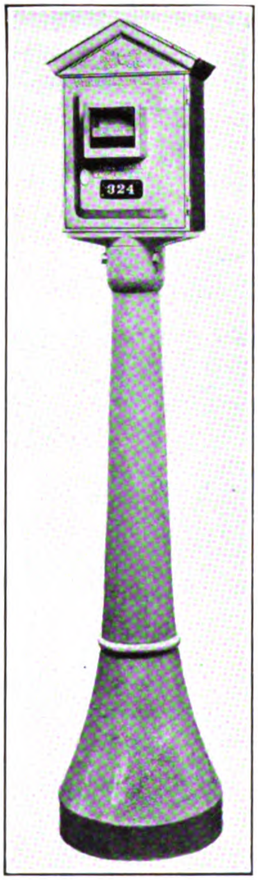


Figure 2—Succession Non-interfering Box with Mounting Post.

When a street box is operated, an electrical circuit is interrupted a certain number of times in accordance with a code number allotted to the box, and the alarm is received at the Fire Station on a gong and a register. The gong repeats the number of the operated street box in a loud resonant tone, which can be heard all over the Fire Station and which directs immediate attention to the alarm and the location of the box sending it. The register makes a permanent record on a paper tape of the number of the box from which the alarm originated.

The paper tape, which is paid out by the register, is collected automatically by a take-up reel and, if required, a time stamp can be added which automatically stamps the tape with the full time and date at which the alarm was received. The arrangements are such that the number of the box is sent twice in succession so that no mistake may occur, and the full code, stamped with the date and time, is left exposed to view on the register tape when the register stops.

The fact that all street boxes are connected together in series gives rise to the possibility of interference if more than two boxes are operated together. To avoid this possibility, and the consequent muddled effect which would be produced at the Fire Station, non-interfering devices may be introduced into the box, in which case succession features usually are added as well. Thus, street boxes fall under two main headings: (1) The plain box, viz., one unequipped with non-interfering devices or succession features, for use in areas where the fire risk is so small that the chance of two boxes being pulled together is negligible; (2) a non-interfering, succession type box which is not only non-interfering with regard to a neighbour box pulled at the same time, but which is also successive in that it will transmit its call to the Fire Station when the other box has left the line free. The non-interfering succession box is favoured in densely populated areas where the risk of two calls being originated on any one circuit at the same time exists.

The movements of the street boxes and Fire Station apparatus are operated electromechanically, powerful main springs being employed to drive the mechanisms with electromagnets to control them in nearly all cases. Ample reserve power is, therefore, always available, and the mechanisms can be made sturdy and consequently reliable in operation.

The electrical portion of the apparatus in the street boxes is mounted on porcelain throughout in order to maintain the highest possible insulation under all circumstances.

In order to secure adequate protection against the most severe weather conditions, the movement of the street boxes is housed in a triple cased iron box. Each case is practically dust tight; and air spaces, which have the effect of reducing to a minimum any likely changes of temperature in the case containing the movement, are provided between the cases. Thus, the deposition of moisture and all the resultant troubles due to corrosion are prevented.

Street Boxes

The outside of the box which houses the non-interfering mechanism is shown in Figure 2. The pull handle is normally covered by a sheet of glass which it is necessary to break before an alarm can be given. In so doing, a frame which carries the sheet of glass is thrown forward under the action of a spring in such a manner as to clear the glass from the vicinity of the pull handle, and so reduce the risk of cut hands due to splintered glass. It is then only necessary to pull the handle forward in order to set the mechanism in operation. Figure 3 shows the door of the outer box open and, on the inside of this door, the lever mechanism which transfers the pull to the inside box. This inside box houses the third and innermost case containing the signaling mechanism and also testing and communicating apparatus for talking or sending telegraph messages to the Fire Station (Figure 4).

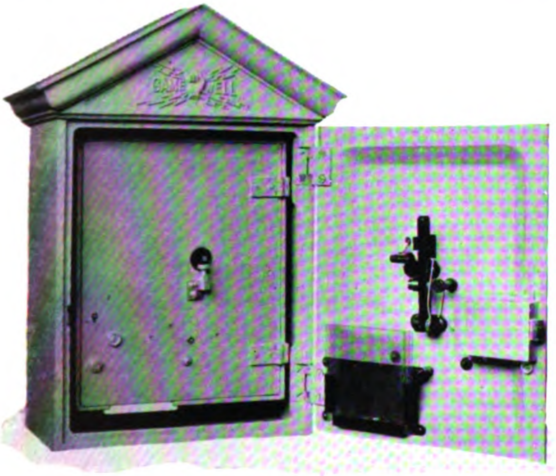


Figure 3—Succession Non-interfering Box with Outer Box Door Open.

A plunger type key is provided for throwing additional resistance into the circuit in such a way that the mechanism can be tested without interfering with the other boxes on the circuit or the station recording apparatus. When the door is closed, the plunger type key and the additional resistance referred to are short-circuited. A lightning protector is provided to protect the apparatus from high potential currents.

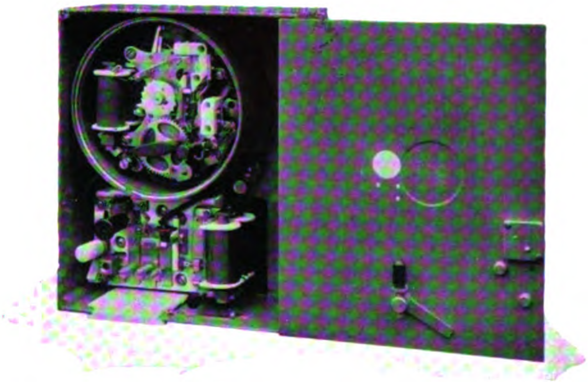


Figure 4—Inside Box of Succession Fire Alarm Box.

The Succession Movement detached from its case is shown in Figure 5. When the starting lever is depressed in response to a pull from the outside of the box, the wheel train starts to revolve and carries round the code wheel in the centre of the movement. If at the time there is no other box sending an alarm signal, the electromagnet will hold its armature and the code on the teeth of the signal wheel will be transmitted to the impulse springs in such a manner as to make and break the line circuit in accordance with the code of the box. This signal is given twice, after which the wheel train is brought to rest and a pair of heavy springs are brought together to make electrical

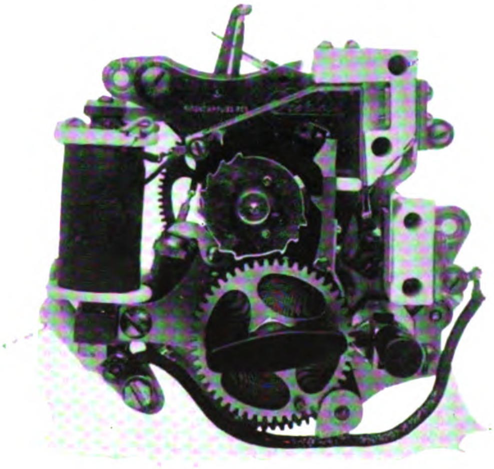


Figure 5—Succession Non-interfering Box Movement.

contact in such a way as to bridge the signaling contacts and the electromagnet which are themselves connected in series. This shunting switch completely short circuits the movement coils when the box is idle. If, however, another box is signaling an alarm when the box under consideration is pulled, the electromagnet releases its armature on account of the intermittent line current and the signaling contacts are locked in the closed position in order not to break the series circuit of the other box signaling. In this case the wheel train continues to rotate, but idly, so that no signals are transmitted, neither does the box get any nearer its position for shutting down. At each revolution of the code wheel the armature is forced up mechanically to the pole face of the electromagnet, and if on any one of these occasions the line is disengaged, the armature will be held to the cores and the normal transmission of the signals will commence. After two effective revolutions of this wheel, the mechanism shuts down and is restored to normal.

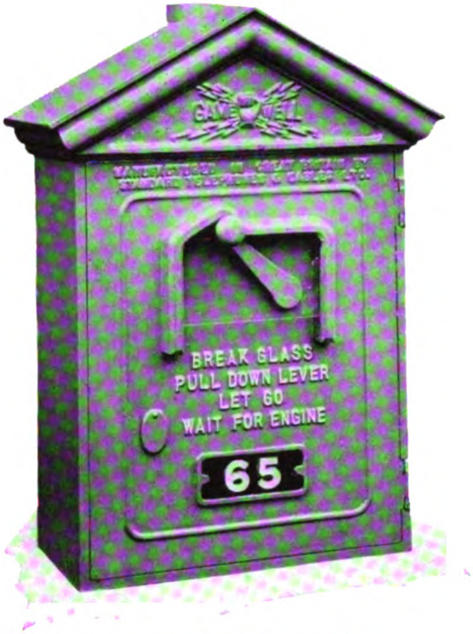

GAMEWELL
MANUFACTURED IN GREAT BRITAIN BY
STANDARD TELEPHONES & CABLES LTD.
BREAK GLASS
PULL DOWN LEVER
LET GO
WAIT FOR ENGINE
65

Figure 6—Plain Type of Box.

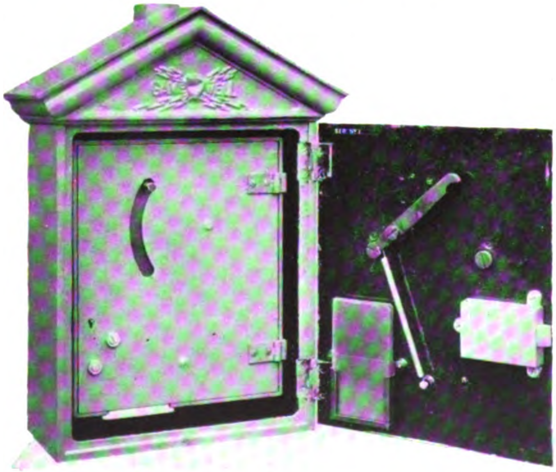


Figure 7—Plain Type of Box. Outer box door open, showing inner box.

The plain street box is illustrated in Figures 6, 7 and 8. It operates on a similar general principle to the succession box, but has no non-interfering apparatus to provide for the case when more than two alarms are sent in at the same time and on the same circuit. The box is operated by means of an arm connected to the shaft on which the main spring is anchored. To send in an alarm, it is necessary to break the glass in the outer door and to pull down the lever, thereby winding up the main spring which drives the clockwork mechanism and rotates the code wheel on the return stroke. The design of the mechanism is such that it is not possible for a succession of pulls on the part of a person giving an alarm to interfere with the rotating mechanism. The testing and connecting apparatus in this box are exactly similar to that of the succession box.

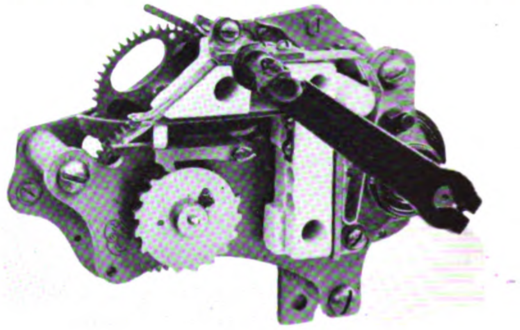


Figure 8—Movement of Plain Type of Box.

Fire Station Apparatus

The Register

To record fire calls from one circuit only, the single circuit register, illustrated in Figure 9, is used and is connected directly in the box circuit. It punches a ¼ inch hole in the tape every time the current is interrupted. When the current is restored the armature of the register's electromagnet is reset ready to trip the mechanism on the next break of the current. Paper one inch

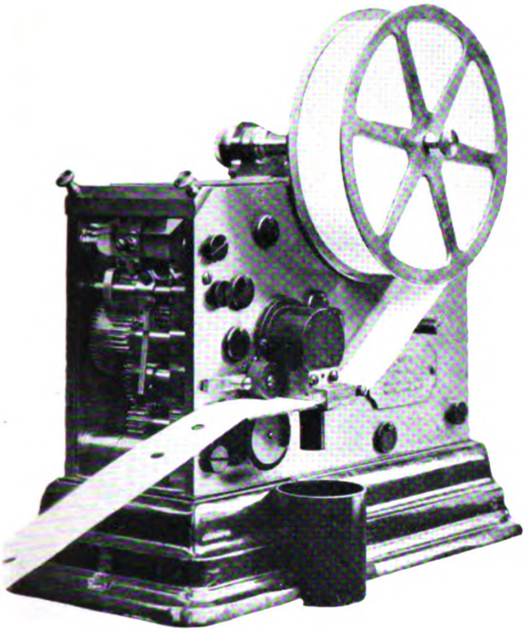


Figure 9—Single Circuit Register.

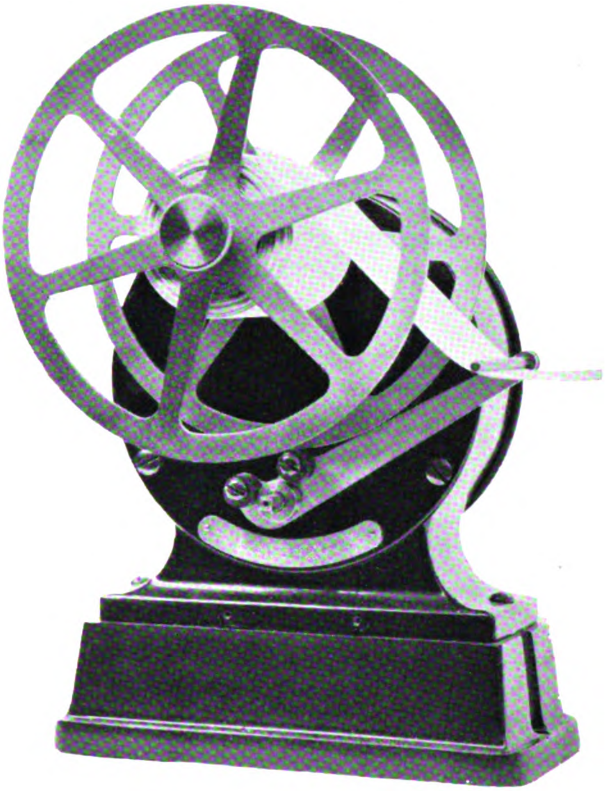


Figure 11—Paper Take-up Reel.

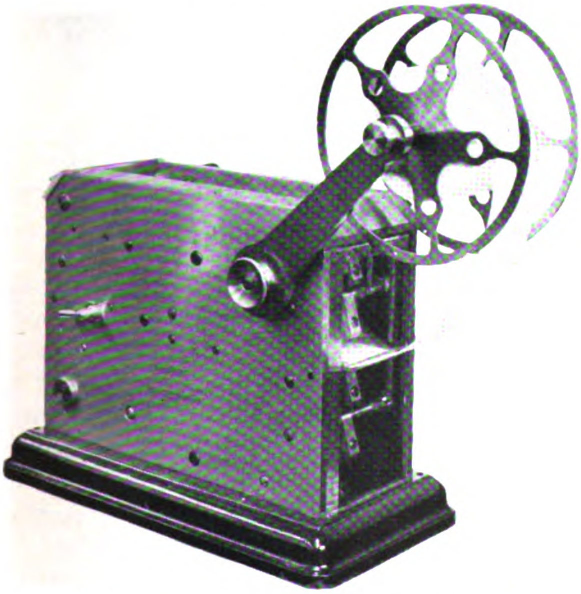


Figure 10—Multi-circuit Register Arranged to Receive Calls from Four Circuits Simultaneously.

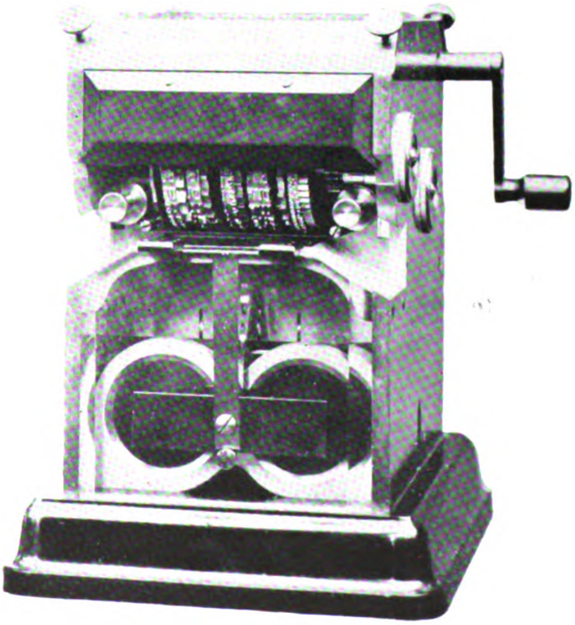


Figure 12—Time and Date Stamp.

wide is used in the recorder and at the completion of the code a local contact is closed, which operates a time stamp in order to stamp the exact time and date when the code is received. This register has two independent wheel trains driven from the same main spring, one to feed the paper forward, the other to drive the punch which is mounted eccentrically on one of the shafts of the wheel train. The "confetti" is collected in a small dust box located at the side of the register.

Figure 13—Register, Time Stamp and Take-up Reel as Mounted at Fire Station.

A different type of register has been designed to receive calls from more than one circuit simultaneously, and up to a maximum of six circuits. It is shown in Figure 10. The register is placed in a local circuit and fed from a 20-volt battery, the operating current being 220 milliamperes. The paper tape used with this register is two inches wide and is fed straight through the body of the recorder where it passes below a series of prickers each connected by a simple link mechanism to a separate electromagnet. Current in any one electromagnet depresses the associated pricker with the result that a triangular hole is perforated in the paper. As with the single circuit register, there is provided a local contact which is closed at a suitable time after the last punch is received on the register and which causes the time stamp to record the time and date on which the last code was received. The register also is fitted with a main spring controlled by an escapement which can be loaded mechanically to run at the correct speed. Here, the only function of the wheel train is to feed the paper forward.

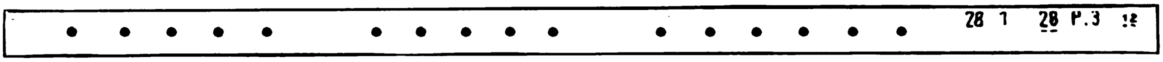


Figure 14—Paper Tape Showing Multi-punchings and Impress of Time Stamp.

The Take-up Reel

The take-up reel, illustrated in Figure 11, is mounted about four feet away from the register, and is arranged to collect the tape as it is fed forward. A brake arm device ensures that all slack in the paper is always taken up, and in case the paper breaks or the reel comes to an end, the brake arm will drop down and still hold the reel from running away. The mechanism merely consists of a main spring and simple wheel train which is connected directly on to the reel itself, the brake being applied at the rim of the reel.

Time Stamp

The time and date stamp illustrated in Figure 12 is mounted close up to the register so that the paper passing through the register to the take-up reel is passed directly beneath a series of type wheels on which are cast the years, months, days, and hours and minutes, both A.M. and P.M. Two electromagnets are used in the apparatus. One presses the paper on to an ink ribbon immediately below the type wheels, and is termed the printing electromagnet; the other is connected directly with the type wheels and to a master clock, and is arranged to receive one minute impulses in order to keep the type wheels at the correct time and date. Figure 13 illustrates the relative positions of the register, time stamp and take-up reel as arranged at the Fire Station, and Figure 14, the tape with multi-punchings and the impress of the time stamp.

GONGS

Gongs six inches in diameter usually are used, but they are manufactured in sizes up to fourteen inches. The six inch gong is illustrated in Figures 15 and 16. It has an electromagnet which, when released by the break of the current in the box circuit, trips the internal mechanism so as to throw the hammer smartly against the bell. It is automatically reset ready for the next break in the circuit. A main spring is used to drive a toothed ratchet which engages two stepping pawls arranged to make the hammer oscillate alternately into the centre of the mechanism and out to the edge of the gong as the ratchet wheel rotates. The electromagnet operates on the ordinary line current of 100 milliamperes.

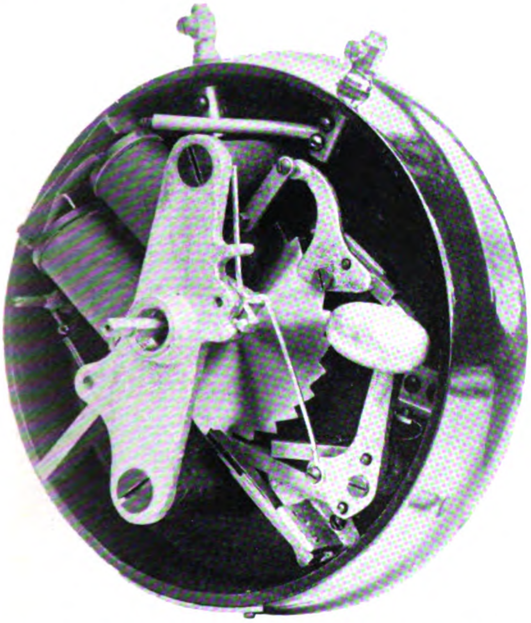


Figure 15—Gong with Bell Removed, showing mechanism.

Batteries and Control Board

Two batteries always are provided for every box circuit, the one being on charge while the other is discharging through the circuit. A make-before-break multiple throwover switch is used to effect the change over. The usual charging and discharging instruments, fuses, line protectors and rheostats are provided, mounted on a slate panel. A voltmeter switch for testing to earth on both sides of the battery enables the Fire Station personnel to make routine tests for earth faults. Since no earth connections normally are used in the Gamewell System, the presence of the single earth has no effect on its operation; but it is usual to make these routine tests at least once a day in order to ascertain that the insulation resistance of the line is being maintained at a good level.

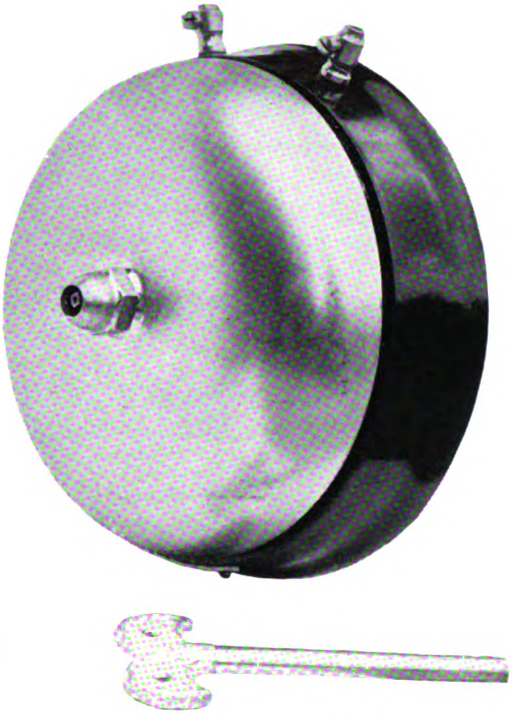


Figure 16—Gong for Audibly Warning the Brigade of the Number of a Fire-alarm Call.

Rotary Automatic Telephone Service for Shanghai

By H. P. MILLER

Commercial Manager, China Electric Company, Ltd.

SHANGHAI, one of the most important trade centers in the Far East and the largest in China, has just completed the cutover of the first 5,000 units of a 7-A Rotary machine switching system. The equipment, which has a capacity of 10,000 lines, is being installed in the Central Exchange of the Shanghai Mutual Telephone Company which serves both the International Settlement and the French Concession.

The Shanghai Mutual Telephone Company was organized with 200 telephones in service in 1900, when the population of Shanghai comprised in the International Settlement and the French Concession was only about 500 foreigners and 345,000 Chinese. At present, there are five exchanges and nearly 25,000 telephones in use, and the population in the area in which the Telephone Company operates has grown to 40,000 foreigners and 1,000,000 Chinese.

It was nearly fifteen years ago that consideration was first given to the use of an automatic telephone system for Shanghai. In 1920 it was decided to install automatic equipment in East Exchange and a few years later a 500 line Ericsson automatic installation was made. Subsequently, it was increased to 1,000 lines. In view of a demand for more up-to-date service and other factors, it was decided also to install automatic equipment in Central Exchange, which furnishes service to the business district. Representatives and officials of the Telephone Company visited many telephone exchanges in Europe and America and made careful studies of the various types of automatic systems in use. As a result, it was concluded that the 7-A Rotary machine switching system was the most satisfactory. In 1924, a contract was entered into with Standard Telephones and Cables, Ltd., covering the installation of the 5,000 lines of 7-A Rotary equipment.

The climate of Shanghai is severe, with temperatures varying from 20° F. at times during the winter to a maximum of 110° F. during the summer. The relative humidity is particularly high, sometimes in the neighbourhood of 80 to 90 per cent for days at a time. These conditions naturally called for specially treated equipment throughout, including anti-rust treatment of all metal work, enameled conductors and impregnated insulation on all cables. Besides these safeguards, it was believed by the Telephone Company and its consulting engineers that more reliable operation and satisfactory service could be secured if the equipment was designed for 24-volt operation. Although this involved practically redesigning the 7-A Rotary equipment, it was taken care of satisfactorily by the engineering staff of Standard Telephones and Cables,

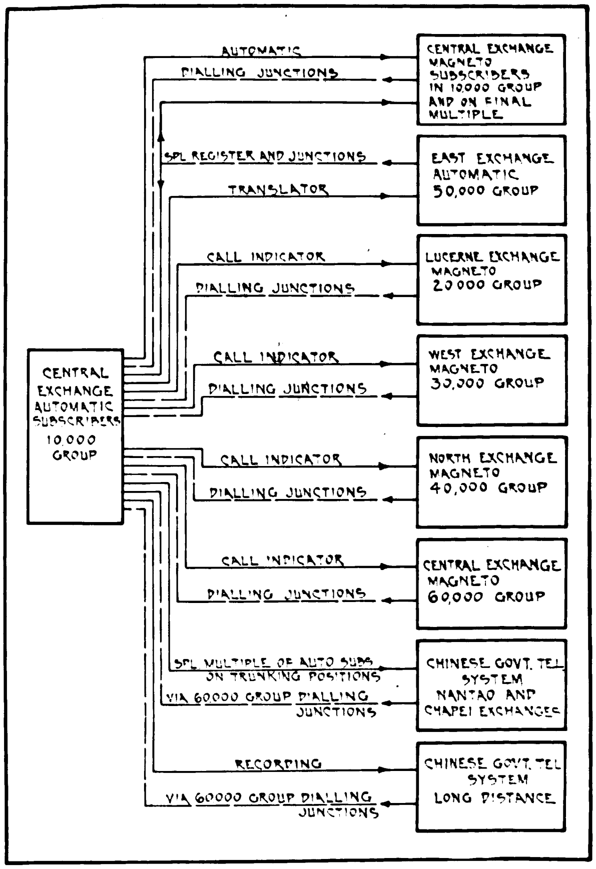

CENTRAL EXCHANGE AUTOMATIC SUBSCRIBERS 10,000 GROUP
AUTOMATIC
DIALLING JUNCTIONS
CENTRAL EXCHANGE MAGNETO SUBSCRIBERS IN 10,000 GROUP AND ON FINAL MULTIPLE
SPL REGISTER AND JUNCTIONS
TRANSLATOR
EAST EXCHANGE AUTOMATIC 50,000 GROUP
CALL INDICATOR
DIALLING JUNCTIONS
LUCERNE EXCHANGE MAGNETO 20 000 GROUP
CALL INDICATOR
DIALLING JUNCTIONS
WEST EXCHANGE MAGNETO 30,000 GROUP
CALL INDICATOR
DIALLING JUNCTIONS
NORTH EXCHANGE MAGNETO 40,000 GROUP
CALL INDICATOR
DIALLING JUNCTIONS
CENTRAL EXCHANGE MAGNETO 60,000 GROUP
SPL MULTIPLE OF AUTO SUBS ON TRUNKING POSITIONS
VIA 60000 GROUP DIALLING JUNCTIONS
CHINESE GOVT. TEL SYSTEM NANTAO AND CHAPEI EXCHANGES
RECORDING
VIA 60000 GROUP DIALLING JUNCTIONS
CHINESE GOVT. TEL SYSTEM LONG DISTANCE

Figure 2—Method of Handling Calls between Central Automatic Exchange and the Other Exchanges in the Area.

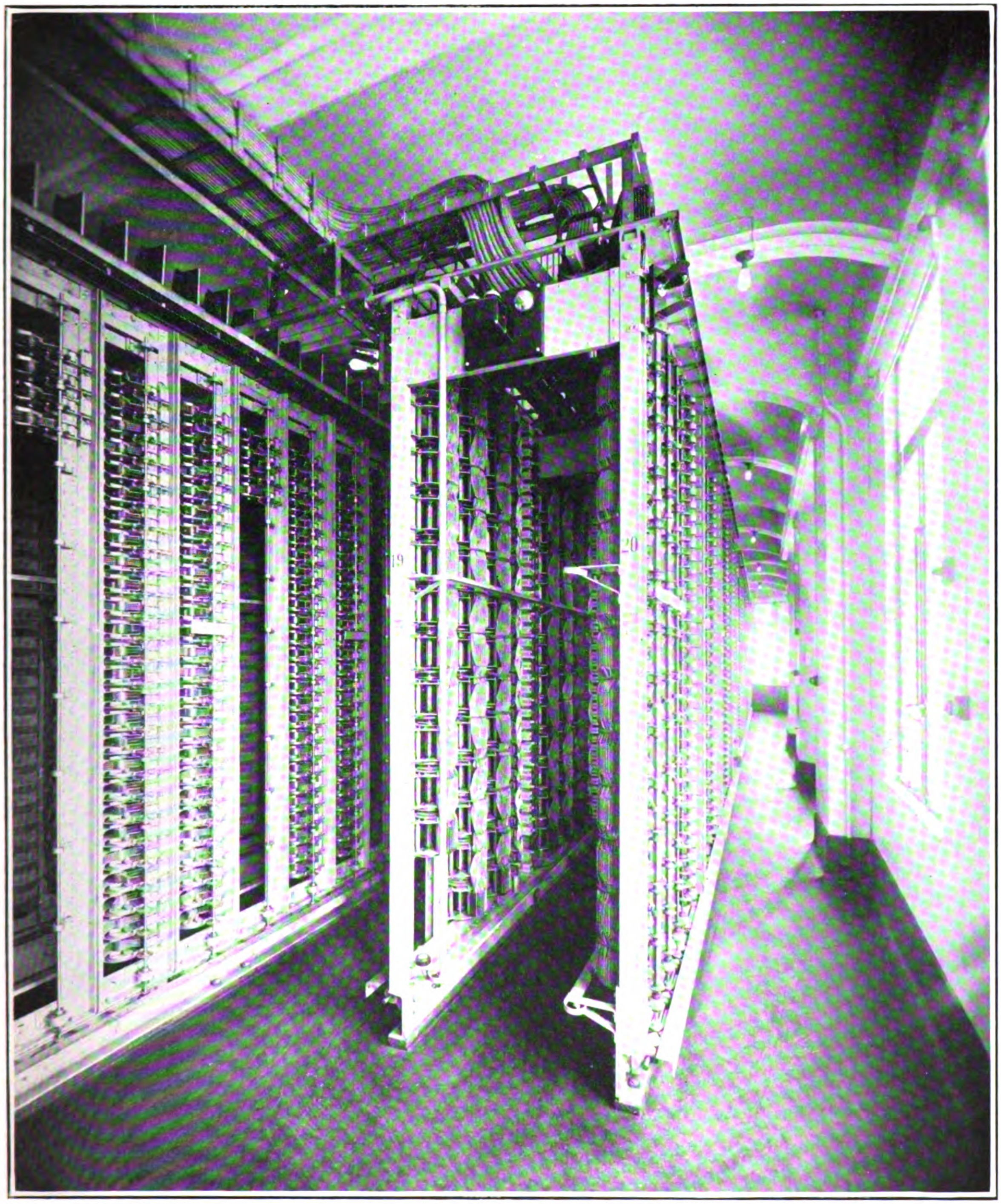


Figure 1—Line Finders and Selectors.

Ltd., London, and the Bell Telephone Manufacturing Company, Antwerp.

Previous to the cutting over of the 5,000 line unit of Rotary equipment, the Shanghai Mutual Telephone Company's network included the above mentioned 1,000 line automatic exchange and four magneto exchanges with switchboards equipped with lamp signals. Much of the outside plant was underground with but little aerial cable or open wire.

The initial Central Exchange automatic installation of 5,000 calling stations was arranged with final selectors reaching the entire group of ten thousand lines (Figure 1). Additional equipment is now being installed so that very shortly there will be 10,000 automatic telephones in Central District. To facilitate cutting over from the manual system to automatic, all the finals were multipled with 10,000 lines of the Central manual at the main frame. This procedure, of course, necessitated the use of considerable additional equipment but it was felt that the expense was fully justified, since automatic telephones could be substituted for manual at the subscribers premises at the convenience of the Telephone Company's staff and as rapidly as desired. It also enabled operators at the manual exchanges to become familiar with the dialing junctions and with methods, illustrated in Figure 2, of handling interexchange calls. It will be noted that dialing junctions are being used instead of semi-B positions at the manual exchanges. Semi-B positions would probably have been more efficient from a traffic standpoint but as these manual exchanges will probably be replaced by automatic equipment within a few

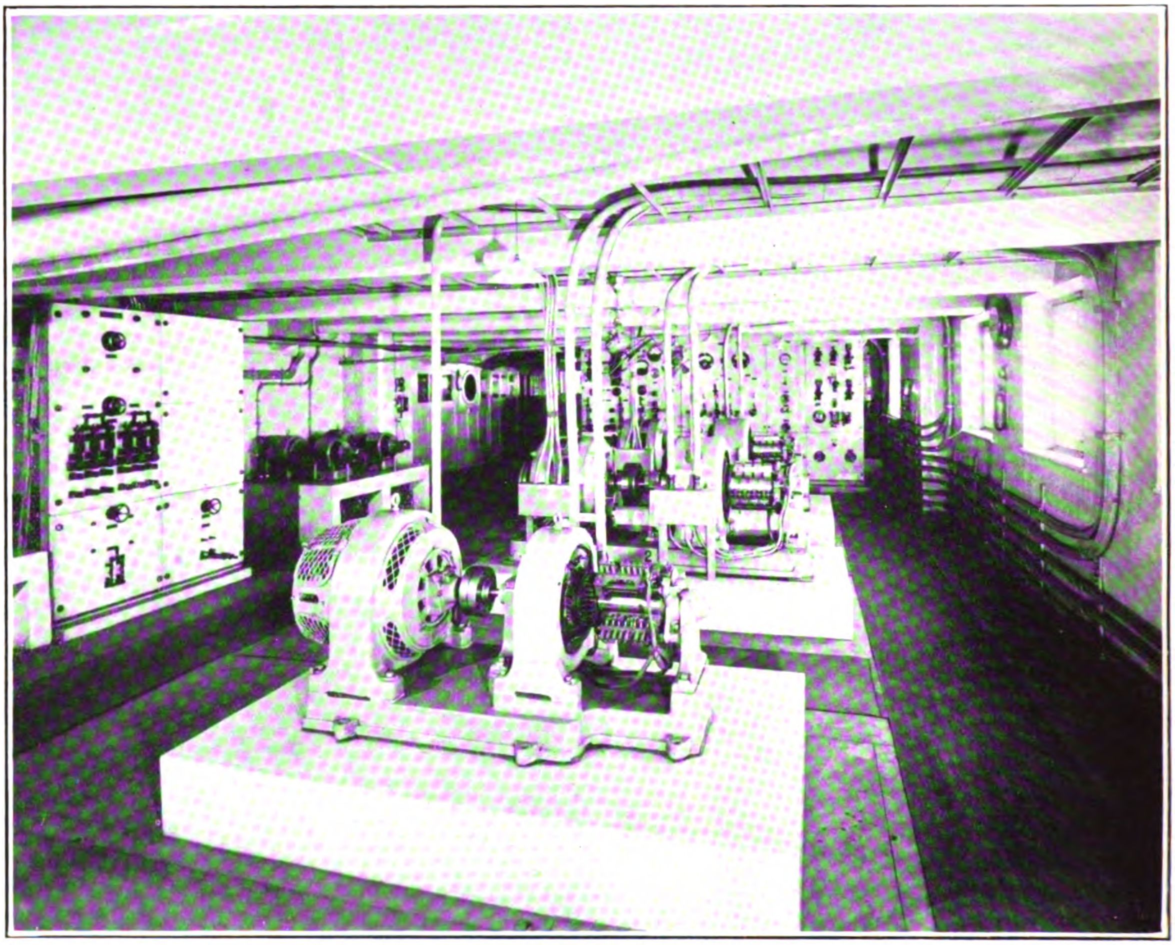


Figure 3—The Power Plant.

years, the additional expense was not considered justified.

Incoming traffic from East automatic exchange to the Central automatic subscribers and also to the magneto subscribers in the 10,000 group is handled through special registers and junctions. Outgoing traffic from Central automatic to East Exchange routes through a translator, designed particularly for this service.

There is an increasing amount of traffic exchanged with the Chinese Government exchanges at Chapei and Nantao. Outgoing traffic from Central Exchange is handled through a special multiple of automatic subscribers (10,000 group) on a trunking position at which some subscribers are barred service. Incoming traffic to Central Exchange is routed via the 60,000 group dialing junctions. Outgoing toll traffic from Central Exchange over the long distance lines of the Chinese Government Telephone Administration is handled through a special toll recording position. Incoming toll traffic, as in the case of ordinary traffic from the Nantao and Chapei exchanges, is routed via the 60,000 group dialing junctions.

The entire 10,000 line automatic group is located on the third floor of the Central Exchange building, the main frame being located directly above on the fourth floor. The power room (Figure 3) is in the basement of the building. Here there is the necessary charging equipment, ringing machines and two 4,000 ampere hour storage batteries, the largest in the Orient. The frame motors are 200-volt 50-cycle single phase A.C. and are fed from the municipal electric service through a suitable switchboard. To provide for an emergency power supply should the ordinary source fail, there is installed in the power room a 200-volt 50-cycle single phase A.C. generator driven by a 24-volt D.C. motor. A relay on the switchboard starts up the motor generator set when the normal supply fails and the motor generator set is automatically cut out of service when the normal supply is again available.

Desk or wall sets with handsets or microtelephones are used exclusively. The dials are of special design, the lower or number plate rotating with the top or finger plate. Most of the dials are marked with Arabic numerals although some bear Chinese characters only (Figure 4). Single line subscribers or those with a single line and one extension telephone only are connected to the new automatic exchange at the present time. In the case of subscribers with a single line and one extension telephone, arrangements are such that the main station, in addition to signalling and talking to the central office, can communicate with the extension station at the same time holding the central office call or connect the extension station with the central office.

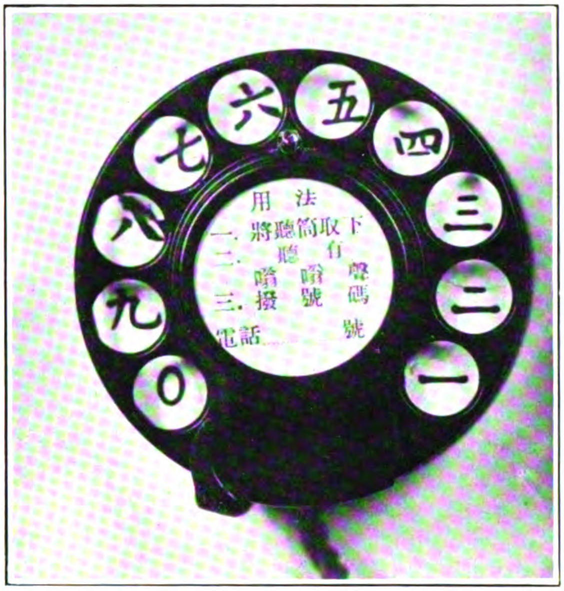


Figure 4—Calling Dials of Special Design. They are marked either with Arabic numerals or Chinese characters.

When the additional 5,000 lines of automatic equipment which is now being installed is put in operation, subscribers with two or more exchange lines will be provided with common battery private branch exchange switchboards which will be equipped with dialing circuits. It is expected that before the end of the year the extension will be in operation with ten thousand telephones connected.

The new automatic equipment which has been placed in operation by the Telephone Company is functioning satisfactorily and the subscribers are highly pleased.

Transatlantic Telephony Between the Institution of Electrical Engineers, London, and the Institute of Electrical Engineers, New York

ON Thursday, February 16, 1928, a demonstration of transatlantic telephony was given between the Institution of Electrical Engineers, London, and the Institute of Electrical Engineers, New York, in joint session. By preliminary agreement, arrangements were made for receiving and for sending telephonic messages from the Council Rooms of the respective institutions and, in the case of London, provision was made by the British Post Office whereby an audience consisting chiefly of electrical engineers could listen in their Lecture Theatre to the proceedings, by the aid of a loud speaker. Immediately preceding the demonstration, a paper was read in New York by Mr. Waterson. This concluded at 3:25 P.M. (10:25 New York). In London the corresponding time from 3 P.M. to 3:20 P.M. was occupied by showing in the Lecture Theatre a film entitled—"Voices Across the Sea." At 3:20 P.M. those who had been invited to attend in the Council Room moved to their places and received a short explanation of the arrangements. This explanation concluded at 3:28 P.M.

After a few preliminary explanations to a corresponding meeting in New York, everything was ready, and by 3:30 the conversation began and continued somewhat as follows:

MR. CHARLESWORTH (New York): Good morning, Colonel Lee, is Mr. Page ready to talk?

COLONEL LEE (London): Good afternoon, Mr. Charlesworth, Mr. Page is ready to talk and I will hand the microphone to him.

MR. GHERARDI (New York): Good morning, Mr. Page.

MR. PAGE (London): Good afternoon, Mr. Gherardi.

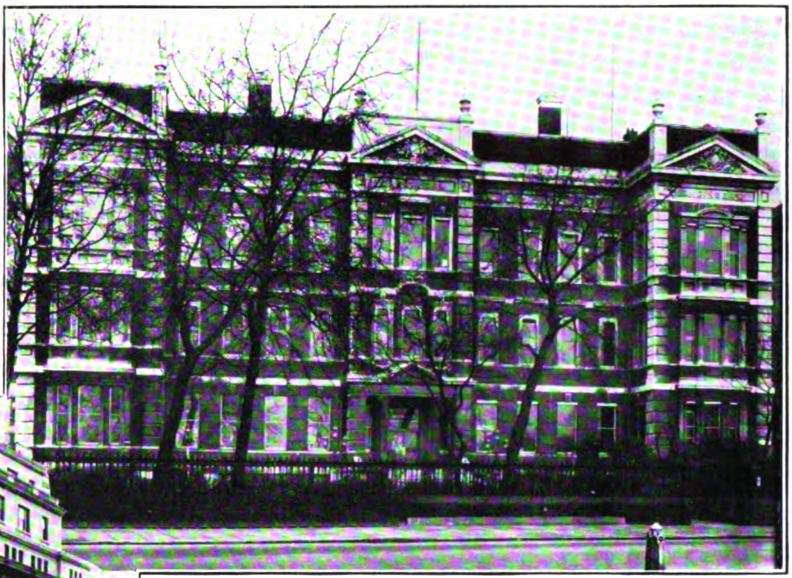
MR. GHERARDI (New York): Mr. Page, it would give us great pleasure if, as President of the Institution of Electrical Engineers—the senior society, founded in 1871—you would act as Chairman of this joint meeting.

MR. PAGE (London): I regard it as a great honour to be asked to take the chair on this historic occasion; it is also a gracious compliment to our Institution, and in accepting, which I do gladly, I desire to thank you, Mr. President, and the Members of the American Institute of Electrical Engineers most heartily. I welcome all present at the meeting now in session, and venture to predict that the proceedings will prove exceedingly interesting and likely to live not only in our memories, but to be quoted by succeeding generations of electrical engineers, as marking an important milestone in the advancement of electrical science. I am sure I interpret the desire of those assembled if I request Mr. Gherardi to address us, which I now do.

MR. GHERARDI (New York): Mr. President and Members of the Institution of Electrical Engineers: On behalf of the American Institute of Electrical Engineers, I extend to you greetings and our best wishes.

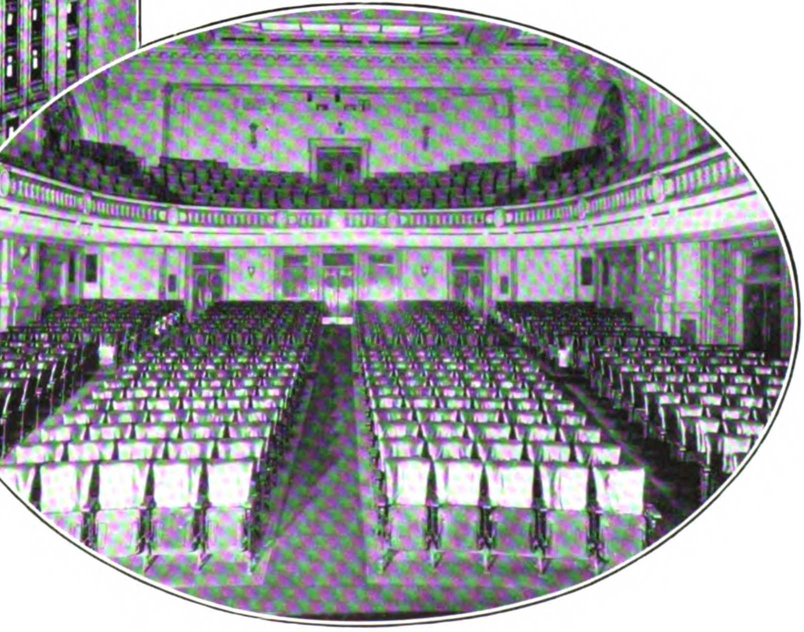
We are meeting here in New York at our Midwinter Convention. In the auditorium of the Engineering Society's Building in New York City, from which I am speaking, there are assembled about one thousand members of our organization from all parts of the United States, from Canada, and from other parts of the New World.

It is with the greatest satisfaction that, as a result of the accumulated work of the scientist, the inventor, and the electrical engineer, it is possible for us to hold this joint meeting—the first of its kind. It is with feelings of deep appreciation and respect that we think of the men who have exemplified the ideals of your organization—Faraday, Maxwell, Kelvin,—and of many others, past and present, who have contributed to electrical engineering and to the scientific foundations upon which it rests. These developments have been notable and have contributed in the greatest degree to the welfare of mankind. One of these developments is the art of electrical communication—the electric telegraph and the telephone. These have made communication independent of transportation, and no longer subject to all of its difficulties and delays. By the telephone, distance has not only been an-



The Institution of Electrical Engineers, London.

The Engineering Societies Building, in which the Headquarters of the American Institute of Electrical Engineers are located and in which New York City Meetings are held.



Auditorium of Engineering Societies Building, New York City.

nihilated, but communication by means of the spoken word has become possible. Starting in 1876 with instruments and lines, which with difficulty permitted communication over distances limited to a few miles, the telephone has been improved year by year until continents have been spanned, and at last, even the limitations of the Atlantic Ocean have been overcome, and today telephone conversation between the two great capitals of the English-speaking world is a reality. We are gratified that transatlantic communication has made this meeting possible; it has added one more to the many ties existing between our two institutions, and has added still another opportunity for friendly communication between us.

Mr. Page (London): Mr. Gherardi and Gentlemen: Please regard me for the time being, not as Chairman, but rather as representing the 13,000 members of the Institution of Electrical Engineers. My first desire is to thank you, Sir, for your most kind message of good will to us all. In turn, we hail the President and members of the American Institute of Electrical Engineers with feelings of the utmost warmth, and of everything included in the term good comradeship.

Owing to the hour at which it has been necessary to hold this meeting falling within the period when the bulk of our members have to be on duty elsewhere, we have perforce had to content ourselves with a smaller gathering in London than that composing your convention. It is, however, of a thoroughly representative character consisting of specially invited distinguished guests, the Council of the Institution, many of whom have traveled long distances to be present, and a large percentage of the members of our Wireless Section.

The telephone must rank as one of the greatest inventions of the nineteenth century, and it has transformed the daily life of all civilized people. Our indebtedness to Graham Bell for the boon he has conferred upon us increases with the years, and his memory, along with that of Franklin and Henry, will be cherished as becomes such benefactors of mankind. It would indeed be a gigantic task to attempt to exhaust the list of those of your society who have contributed so largely to the progress of electrical science, and I must content myself by paying tribute to a great institution which has given proof time and again that engineering is truly international. It cannot be questioned that we are living in a period of extraordinary change due to scientific discovery, and in no field has the advance been more marked than in that of the communication engineer. The commercial radio services thus placed at our disposal assure closer and closer association between the English-speaking races, a new spice is added to life and the bonds of friendship materially strengthened. I rejoice that our two institutions can combine in the future even more effectively than in the past, and that this is the outcome of the splendid work done in one of the branches of our own profession.

I will now resume my chairmanship and call upon Dr. Jewett who is one of the Vice Presidents of the American Telephone and Telegraph Company, and a past President of the American Institute of Electrical Engineers.

Dr. Jewett (New York): Mr. Chairman, Mr. Gherardi, and Fellow Members of the Institution of Electrical Engineers and of the American Institute of Electrical Engineers: The opportunity which this occasion offers of addressing jointly two widely separated groups of engineers whom, in times past, I have addressed *vis-à-vis*, in London and New York, affords me the liveliest satisfaction. I am gratified to participate in an event which marks both a notable advance in electrical communication, and a pioneer demonstration of a wider use for electrical communication. I am frankly pleased that in common with numerous associates on both sides of the Atlantic, it has been my good fortune to play a part in the development work which has made this occasion possible.

Colonel Purves and Mr. Gherardi will remember, and the rest of you will be interested to know, that in London more than a year ago, when we were engaged in final considerations preliminary to the opening of commercial transatlantic telephony, we discussed details of just such a meeting as this. That our discussion should have been serious and not a pleasant mental diversion, at a time when the channels of communication were not in operation, is a striking evidence of the sound basis which underlies present-day electrical engineering. The fact that we saw and appraised the many obstacles to be overcome did not in the least diminish the assurance with which we talked of and planned for a distant event. While, therefore, the present occasion is highly gratifying to the engineers whose work has made it possible, it is in no sense a surprise. Success on this occasion is significant also in that it is the tangible evidence of a co-operation both intimate and full between men so situated as to make co-operation difficult. On behalf of my associates in America, I salute our associates in England.

(The Chairman (London), then called upon Colonel Purves, Vice President of the Institution of Electrical Engineers and Engineer-in-Chief of the British Post Office.)

COLONEL PURVES (London): Mr. President, Mr. Gherardi, Dr. Jewett and Gentlemen: It is an honour and a privilege to be associated with this notable event, which one can justly feel is breaking new ground in the advance of nations towards closer relationship. It is a great thing that two large assemblies separated by wide expanses of ocean, can join themselves together as we are doing now, and interchange their thoughts and ideas by the simple and natural medium of direct speech to a combined audience. It opens up the prospect of results which thrill the imagination, and which are bound to be beneficient, and to conduce, by the way of clearer mutual understanding, to the good of mankind.

On this first occasion it is inevitable that the many professional interests which our two institutions share—and which we should dearly like to talk over with each other—should be pushed a little into the background, and that we should find ourselves preoccupied mainly with the wonder of the thing itself. At our meeting here in London, we have just been shown a motion picture which illustrates in a very vivid and interesting way the initiation and progress of a transatlantic telephone conversation between San Francisco on the Pacific Ocean, and Plymouth in old England. We were not able—not yet able—to place it simultaneously before the eyes of you who are sitting there in New York, but some of you, at least, have seen it already. The greater part of it was made on your side, and I have to thank your President very heartily for letting us have the completed film. It helps one to recall, and to visualise, the remarkable series of new electrical developments—most of them things of only yesterday—which have combined to make this evening possible. The radio art has given us its essential basic principles, and the high-power amplifying tubes, which over here we call "valves"; long distance telephony has contributed a host of new devices which are equally essential, and specialised broadcasting has given us the loud speaking receiver. As we sit and talk to each other, our speech is launched into the air, by the radio transmitting stations at Rugby and at Rocky Point, with an electromagnetic wave energy of more than 80 horsepower, and I may add that the combined effect of the various refinements and special devices included in the transmitting and receiving systems is to make the speech carrying efficiency of each unit of this power many thousands of times greater than that of an equivalent amount of power radiated by an ordinary broadcasting station. Many further improvements are still being studied.

I should like to express the feelings of great personal pleasure with which I am listening this evening to the voices of my old and valued friends of the American Telephone and Telegraph Company, Mr. Gherardi, Dr. Jewett and General Carty, and to assure them and their colleagues, both on my own behalf and on behalf of the engineering staff of the British Post Office, that the increased opportunities of co-operation with them which the development of the transatlantic telephone system has afforded us, are appreciated in a very high degree. We have to thank them for much helpful counsel, in this, and in many other matters, and we look forward with great pleasure to a continuance of our close association with them on the long road forward, over which we still have to travel together.

THE CHAIRMAN (London): We are delighted to have with us in New York, General John J. Carty, Vice President of the American Telephone and Telegraph Company, and Past President of the American Institute of Electrical Engineers. General Carty is widely regarded as the doyen or, to be more correct, the Dean of the telephone engineering profession, and we shall be glad if he will say a few words and propose a resolution on the subject of our joint meeting.

GENERAL CARTY (New York): Whereas, On this sixteenth day of February, 1928, the members of the Institution of Electrical Engineers assembled in London, and the members of the American Institute of Electrical Engineers assembled in New York, have held, through the instrumentality of the transatlantic telephone, a joint meeting at which those in attendance in both cities were able to participate in the proceedings, and hear all that was said, although the two gatherings were separated by the Atlantic Ocean; and as this meeting, the first of its kind, has been rendered possible by engineering developments in the application of electricity to communication by telephone; therefore,

Be It Resolved, That this meeting wishes to express its feelings of deep satisfaction that, by the electrical transmission of the spoken word, these two national societies have been brought together in this new form of international assembly, which should prove to be a powerful agency in the increase of good-will and understanding among the nations; and

Be It Further Resolved, That a record of this epoch making event be inscribed in the minutes of each society.

THE CHAIRMAN (London): Sir Oliver Lodge, who needs no introduction, is sitting beside me, and I have asked him to second the motion.

SIR OLIVER LODGE (London): It is surely right and fitting that a record of the transmission of human speech across the Atlantic be placed upon the minutes of those societies whose members have been instrumental in making such an achievement possible, and I second the proposal that has just been made from America.

All those who in any degree have contributed to such a result—from Maxwell and Hertz downwards, including all past members of the old British Society of Telegraph Engineers—will rejoice at this further development of the power of long distance communication. Many causes have contributed to make it possible. That speech is transmissible at all, is due to the invention of the telephone. That speech can be transmitted by ether waves is due to the invention of the valve, and the harnessing of electrons for that purpose. That ether waves are constrained by the atmosphere to follow the curvature of the earth's surface is an unexpected bonus on the part of Providence, such as is sometimes vouchsafed in furtherance of human effort. The actual achievement of today at which we rejoice, and which posterity will utilise, must be accredited to the enthusiastic co-operation, and to the scientific and engineering skill of many workers in the background, whose names are not familiar to the public, as well as to those who are well known.

The union and permanent friendliness of all branches of the English-speaking race, now let us hope more firmly established than ever, is an asset of incalculable value to the whole of humanity. Let no words of hostility be ever spoken.

THE CHAIRMAN (London): Gentlemen, you have heard the Motion proposed by General Carty, and seconded by Sir Oliver Lodge. I now put it to the joint meeting. "Those in favour." "Contrary." "Carried unanimously."

THE CHAIRMAN (London): I suggest, Mr. Gherardi, that we now adjourn the meeting. I feel that it has been eminently successful and that we should regard it as the forerunner of many more to come.

THE CHAIRMAN (London): That is all the business, gentlemen. The meeting is adjourned. Good-bye.

The demonstration proved, in the most satisfactory manner, the complete feasibility of holding a joint session between two corporate bodies, even when they are separated by an ocean.

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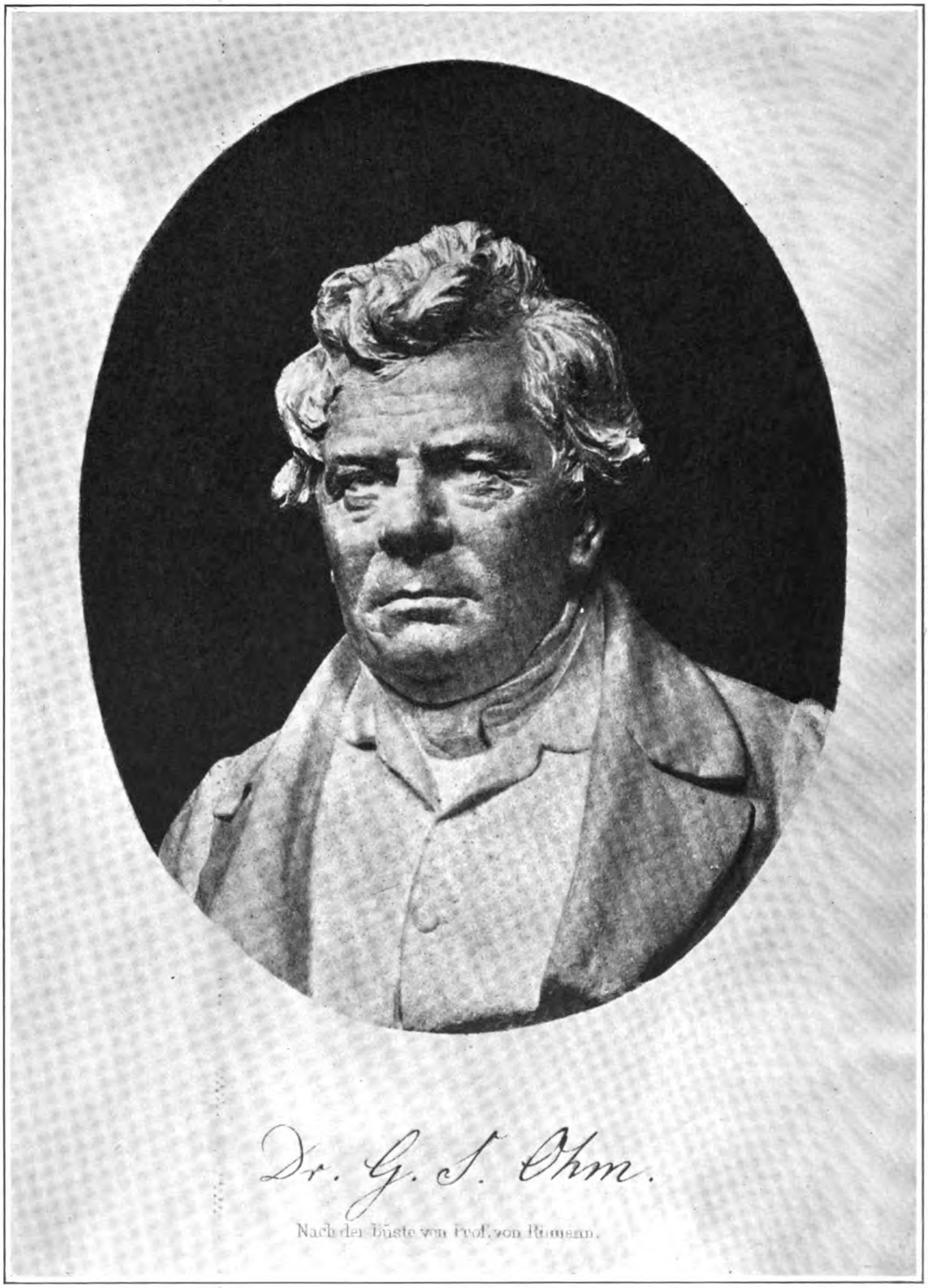

Dr. G. S. Ohm.
Nach der Büste von Prof. von Rümann.

Portrait of G. S. Ohm, from a Bust by Rümann

Pioneers of Electrical Communication

Georg Simon Ohm—VII

By ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

A CENTURY ago, the science and practice of electrical measurement, and the principles of design for electrical instruments scarcely existed. With a few exceptions, ill-defined expressions relating to quantity and intensity, combined with immature ideas of conductivity and derived circuits, retarded the progress of quantitative electrical investigations. Yet, amidst this confusion, a discovery had been made that was destined to create order out of chaos, to convert electrical measurement into the most precise of all physical operations, and to aid almost every other branch of quantitative research. This discovery resulted from the arduous labours of Georg Simon Ohm.

So completely has his work now merged into general knowledge, that his life is lost sight of in a law, and his name in a unit. Writings, all too brief, of his friends Bauernfeind and Mann enable some of the scattered details of his personal history to be ascertained. Relics of his laboratory apparatus, few as they are, give hints of the circumstances in which he carried out his researches. Fortunately, however, in contrast with the broken narrative that tells of his career, there exist his published scientific memoirs, collected with such care and comprehension by Eugene Lommel, that Ohm's achievements are established more firmly than they might have been if every detail of the sombre history of his honourable life had run the gauntlet of the cyclopaedias. To these memoirs must be added the volume of reprints of certain of his letters and other documents which, thanks to the industry and zeal of Ludwig Hartmann of Munich, were collected and printed as a tribute to Ohm on the occasion, in 1927, of the centenary of the publication of the immortal treatise on the electric circuit.

Ohm belonged to a German burgher family, from father to son, locksmiths. His great grandfather was Wilhelm Ohm, of Westerholt, near Münster, in Westphalia. His grandfather was Johann Vincentius Ohm, a journeyman locksmith, who settled first at Cadolzburg; there he married, but in 1764 he made his home in the university town of Erlangen, Bavaria, where he obtained citizen rights. Johann Vincentius had two sons. The elder, Johann Wolfgang, born in 1752, was apprenticed as a locksmith in 1776, and after ten years of wandering as a journeyman he returned to Erlangen, where, in 1785, he became a master locksmith. On January 24, 1786, this Johann Wolfgang Ohm married Fraulein Beck, or Beckin, the daughter of a tailor. They had seven children. The first child of this marriage was Georg Simon Ohm who, according to the most trustworthy authorities, was born on March 16, 1789. A second son, Martin (junior) was born in 1792. In the late summer of 1799, when Georg was but ten years old, their mother died. Of the children, only three grew up; these were Georg Simon, Martin (junior) and Elizabeth Barbara. Martin (junior), it must suffice here to observe, became a distinguished mathematician, and a Professor of Mathematics at the Military College, Berlin.

The younger son of Johann Vincentius Ohm was Martin (senior), born in 1763, i.e., a year before the settlement of Johann Vincentius in Erlangen. This Martin (senior) similarly became a locksmith in Erlangen; he married on February 23, 1789, at the Neustädter Church at Erlangen, Elizabeth Sabina Krug, the daughter of a peasant from the Uehlfeld district. They had five children, none of whom survived infancy. The death of his wife soon followed. On June 23, 1800, he married Sabina Katharina Frasz, a hosier's daughter, and on February 16, 1801, a daughter was born. Martin (senior) Ohm survived the birth of this daughter only a few weeks. He died on April 5, 1801, at the age of 37 years, 7 months and 23 days. He was godfather to his nephew Martin (junior) the son of Johann Wolfgang Ohm.

These details help to dispel doubts concerning the birthplace and the dates appertaining to

Georg. It is remarkable that the records of one who devoted his whole life to precision should call for so much hesitancy in acceptance, but the tablet upon the house where he is alleged to have been born, and the inscription upon his tombstone, are discordant with his history. Moreover, he could scarcely call his name his own. The date and place of birth have recently been investigated by Dr. Deuerlein of Erlangen. His account of the matter was published in a supplement to the "Erlanger Neueste Nachrichten" of June 25, 1927. He found, in the Register of the Evangelical Lutheran Church of Erlangen, Neustadt, the entry of baptism:

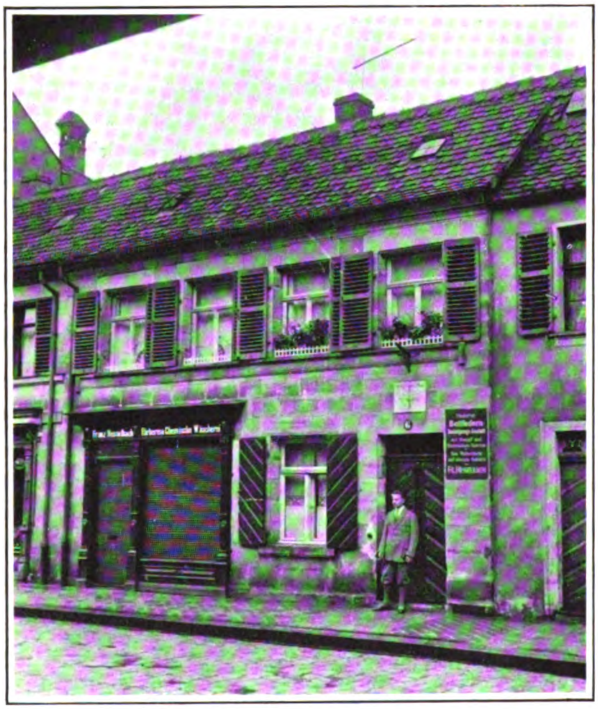


Figure 1—No. 6 Fahrstrasse, Erlangen.

"1789 Martius den 18 t. (wurde getauft) Johann Simon, Mstrs. Johann Wolfgang Ohms, Bürgers und Schlossers dahier, und seiner Ehefrau Maria Elisabetha geb. Beckin von hier Söhnl. geb. den 16. Abends um 3 Uhr. Gev. war Mstr. Johann Simon Beck, Bürger und Schneider dahier, der kindbetterin Bruder."

[1789 March 18th (was christened) Johann Simon —son of Johann Wolfgang Ohm—citizen and locksmith of this district—and of his wedded wife Maria Elizabetha, formerly Beckin of this district. The child was born on the 16th at 3 o'clock in the afternoon. Godfather was Mr. Johann Simon Beck, citizen and tailor of this district, brother of the child's mother.]

This leaves no doubt that the date of birth was March 16, 1789, and that the boy was christened Johann Simon. The name by which he was subsequently known was Georg Simon—possibly to avoid its being mistaken in the family for that of his father, Johann.

The house in Erlangen upon which the memorial tablet is placed is No. 6, Fahrstrasse (Figure 1). From the town records it is known that this house was built in 1733. Its first occupant was the builder of it, Joh. Gg. Held, who sold it to the hatter, Leonard Hofmann. From October, 1754 it was owned by the tobacconist, Andreas Wölckel. He died and left a widow who on March 1, 1779, transferred it to Elias Reinhard, a hosier, from whom it passed by inheritance on June 18, 1782, to Johann Georg Bauer, a locksmith. Two years later it was sold to Johann Friedrich Schwarz, a master white-washer. On March 31, 1791, it was sold to Johann Melchior Günther, a furniture maker, and the Günthers retained it into the nineteenth century. Consequently, No. 6 Fahrstrasse was never possessed by the family of Ohm. There is no evidence that they ever entered it.

The investigation next turns to No. 11 Fahrstrasse (Figure 2), and to No. 20 Friedrichstrasse. No. 11 Fahrstrasse was built in 1724. It passed into possession of Link, the hosier, and it was sold by him on September 7, 1790, to Johann Wolfgang Ohm who there resided and established a locksmith's workshop. No. 20 Friedrichstrasse was built in 1719, and in the middle of the eighteenth century it was owned by Leonard Heinrich Kühn, a tailor. In 1799 it was owned by the master locksmith Johann Vincentius Ohm. On May 3, 1801, after his death, it was taken over by his son Johann Wolfgang—the father of Georg and Martin (junior). As Martin (junior) was born on May 6, 1792, it must be concluded that his birth took place at No. 11 Fahrstrasse—not at No. 6 Fahrstrasse.

Georg Simon was born on March 16, 1789—where, nobody knows, for the residence of his parents before September 7, 1790, has not been traced. His sister, Elizabeth Barbara, born on

July 24, 1794, married on June 7, 1824, the locksmith Konrad Fichtbauer (or Füchtbauer). This worthy man appears to have entered wholeheartedly into the matrimonial contract; for with Elizabeth Barbara he took over the Ohm locksmith workshop, and the two Ohm houses—No. 11 Fahrstrasse, and No. 20 Friedrichstrasse. They had a son who inherited scientific propensities. He became Dr. Füchtbauer, chief member of the educational council and Rector of the Nuremberg Industrial College. By the courtesy of the Director of the Deutsches Museum, Munich, relics of some of the origina apparatus of Georg Simon Ohm are here illustrated, Figures 3 to 7 inclusive; and it is to be remarked that these relics were acquired by the Museum from the Füchtbauer family of Nuremberg, in October, 1904.

In view of these investigations, the words on the stone tablet above the portal of No. 6 Fahrstrasse (Figure 1), may require amendment. They read:

Georg Simon Ohm
Physiker
Hier geb. 16. III. 1789.
Martin Ohm
Mathematiker
geb. 6. V. 1792

[George Simon Ohm
Physicist
Born here. 16. III. 1789.
Martin Ohm
Mathematician
born 6. V. 1792]

The house also bears a notice explaining that upon the premises feather beds are cleaned by steam and by electrically driven machinery. This association of the house with the great electrician constitutes the whole of the evidence.

The father of Georg and Martin was a man of exceptional ability. In his wanderings as a locksmith, he had studied philosophy and mathematics. This had brought him into touch with Professor Langsdorff of Heidelberg who had gone there from Erlangen. Under their father's guidance, the motherless lads made progress, and the attention of Langsdorff was directed to their aptitude. He predicted that history would repeat itself in them as a pair of brothers Bernoulli. Subsequent events accorded with his prophecy. Stimulated by this encouragement, the father decided to give them University education, upon the understanding that they must apply themselves also to become skilled locksmiths.

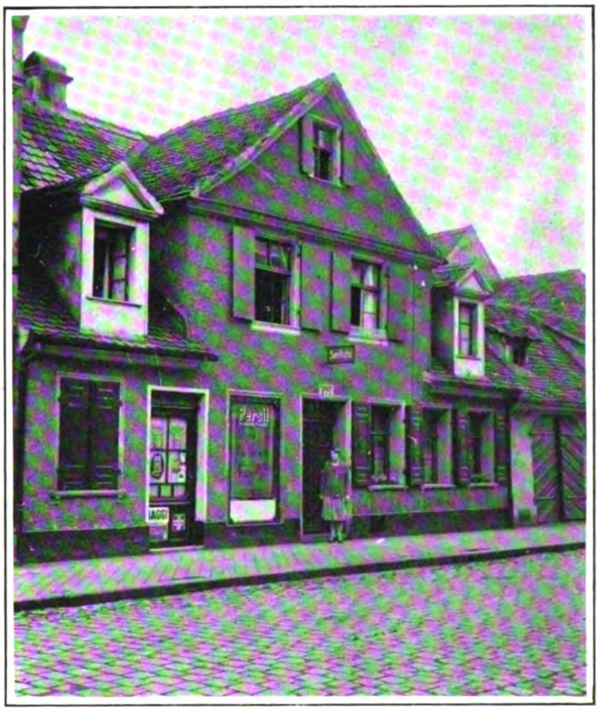


Figure 2—No. 11 Fahrstrasse, Erlangen.

For one year Georg attended the Gymnasium of Erlangen. At Easter, 1805, he entered Erlangen University (Figure 8); on May 3, 1805, he matriculated in Philosophy. His studies were immediately directed to mathematics and physics. Unfortunately, lack of means limited him to but three Terms at the University. At the end of September, 1806, by the services of the bookseller Walther, he obtained a post as a mathematical tutor at a school kept by Zehender, a clergyman in Gottstadt, Switzerland. Soon afterwards, the master of the school wrote to Walther:

"Ich habe beim ersten Anblick des achtzehnjährigen kleinen und schmächtigen Junglings nicht glauben können, dass dieser der empfohlene Lehrer sei, aber mich bald von dieser Tüchtigkeit und Brauchbarkeit überzengt."

[When I first looked at the eighteen year old small and delicate youth, I was unable to believe that he was the teacher recommended, but I was soon convinced of his proficiency and usefulness.]

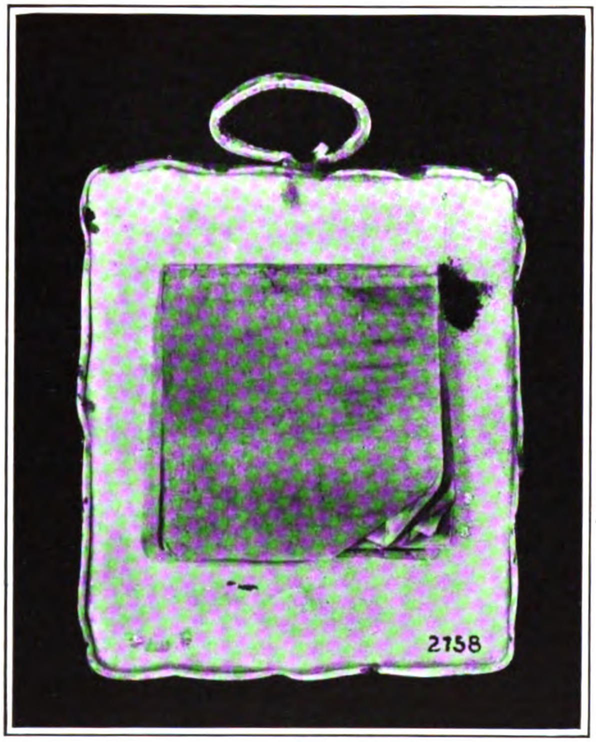


Figure 3—Relic of Ohm's Apparatus. A leather pad upon which he cut gold-leaf for his electroscopes. A book of gold-leaf.

In other words, at first sight he could not believe that this small and weakly youth of 18 could be the teacher recommended, but he soon became convinced of his thoroughness and usefulness. After the third half-year at Gottstadt, Georg went to Neuchatel with the object of taking private lessons in mathematics and conversational French. It was at this period that, upon the advice of his old friend, Professor Langsdorf, he studied the works of Euler and Lacroix. At Easter, 1811, however, he returned to Erlangen and on October 25th of that year he obtained there the degree of Doctor of Philosophy. His inclination was still towards physics, and his special subjects were now mechanics, light, and particularly colour. For three terms he read mathematics, but for reasons of economy he had again to shoulder what to him was the irksome yoke of a teacher.

He was aware that Professor J. S. Schweigger, of Erlangen, had held an appointment at Bayreuth and had since been called to the chair of Mathematics and Physics at Nuremberg. In November, 1811, he accordingly wrote to the authorities at Bayreuth to offer his services, but the result was discouraging He remained at Erlangen, and on July 28, 1812, addressed a letter to the King of Bavaria praying for employment as a teacher. In consequence, on December 16, 1812, Ohm became a tutor at the Realstudienanstalt at Bamberg. There he remained, impoverished and miserable. From the depths of despair he wrote repeatedly to the King and to the authorities, but from the uncongenial conditions there was no escape.

It must be remembered that the year 1813, critical in the history of Europe, brought Germany to the storm-centre of the struggle against Napoleon. Upon Erlangen's 8,000 inhabitants, 33,685 troops were in that year billeted. In addition to the threat from without, there was anxiety lest civil war should arise in Bavaria in favour of Prussian rule. Georg was then 24, of military age, but either upon the grounds of philosophy, physical unfitness, or natural reluctance, he stood aside from military service.

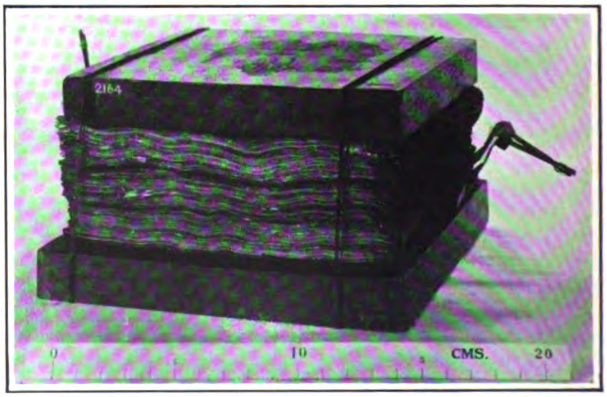


Figure 4—Relic of Ohm's Apparatus. A dry-pile battery, probably of Zamboni type.

In the Spring of 1817, he published his first book. He dedicated it to the memory of his father and gave to it the impressive title, "Grundlinien zu einer zweckmässigen Behandlung der Geometrie als höheren Bildungsmittels an vorbereitenden Lehranstalten," and he sent a copy to the King of Bavaria, beseeching him to grant amelioration of circumstances. The royal reply was as carefully calculated, but more tactful: there was no appointment vacant, but the book had been placed in the library.

Copies of the "Grundlinien" were sent to other reigning monarchs, and amongst them, fortunately, to King Friedrich Wilhelm III of Prussia, who looked with favour upon the application. Ohm therefore left the land of his birth, Bavaria, and in the Autumn of 1817 took up his quarters in Cologne as Oberlehrer in Mathematics and Physics at the Royal Konsistorium. There he found friends and apparatus, a library, and above all, greater freedom, response, and appreciation. The physical apparatus at the Jesuit Gymnasium of Cologne enabled him to proceed with the investigation of the galvanic circuit. He applied himself with complete devotion to his duties, and it is pleasant to record that, in addition to his normal remuneration, he received in October, 1822, a "gratifikation" of 100 Thalers in recognition of his special services.

His influence and his teaching were now, as in his future career, inspiring. Years afterwards, one of his students wrote:

> ". . . seine Art und Weise, sein frisches gesundes Wesen steht mir lebendig vor der Seele, und es gehen selten Wochen, nie Monaten voruber, ohne dass ich an Sie denken muss."
>
> [His nature and manner, his fresh healthy disposition, remain vividly impressed upon my soul; seldom do weeks, and never months go by, but I must think of him.]

His zeal never flagged; he directed his students towards the object which his own genius sought. For a long time his choice alternated between mathematics and physics—mathematics that leads through the mysterious to the wonderful, physics without which mathematics can accomplish little. After the manner of the pioneers, he took care that his mind should not drift. He chose a direct object, and for that, with the utmost skill, he steered. His direct object at Cologne, was the investigation of the galvanic circuit. He there investigated the relative conductivities of metals, the theory of the galvanometer, and by experiment, the law of flow of electricity in conductors. In April, 1826, he realised, however, that if he could break away completely from the restraints of teaching, he could establish the truth concerning electrical circuits. So convinced was he of this, that he requested the authorities to grant him leave of absence for a whole year, undisturbed. Leave was accorded in a most gracious and generous manner, and he betook himself to his brother's house at Berlin. He was probably actuated also by a second motive, for notwithstanding his happy surroundings at Cologne, he was conscious that his achievements deserved recognition in the form of an appointment to a professional chair, and on December 15, 1818—

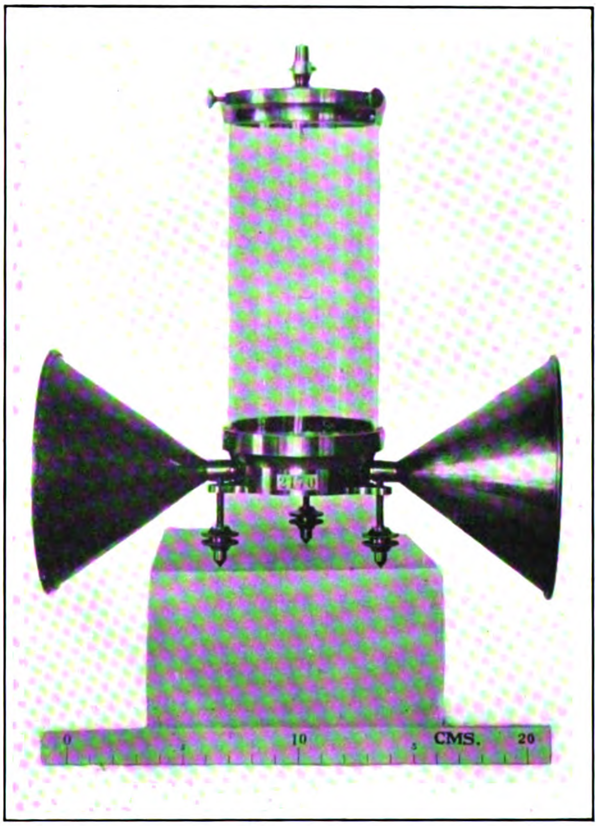


Figure 5—Thermo-galvanometer Used by Ohm. It contains two rectangular bars, probably one of bismuth and the other of antimony, one above the other, at a distance sufficient to allow the lower magnet of an astatic needle to swing between them. The ends of the bars are soldered together, and the upper bar has a longitudinal saw-cut through which the lower suspended magnet can pass to its proper level. The funnel-shaped reflectors are directed towards the solderings.

only a year after his arrival in that city—he had written to the Royal Prussian Konsistorium requesting that his case might be kept before them in this respect. If he could now produce something tangible, both objects would be secured. The tangible result of his sojourn in Berlin was, in fact, his book, "Die galvanische Kette, mathematish bearbeitet," which was published in Berlin in May, 1827.

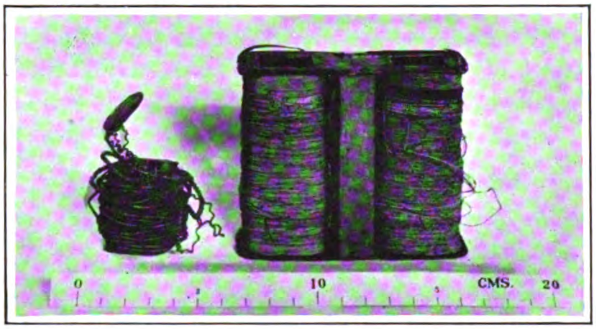


Figure 6—Relics of Ohm's Apparatus. Bobbins wound with wire.

Confirmation of his law of electrical circuits described in this treatise, came from Fechner of Leipzig, from Pfaff of Erlangen, and from Poggendorff of Berlin. Criticism, however, was levelled against it, gently enough by Kämtz of Halle, but more provokingly by G. F. Pohl in the *Jahrbücher für wissenschaftliche Kritik*, to which Ohm forcibly replied. Scientific strife led to the breaking off of friendly relations, and Ohm, taking into account the true nature of the opposition, relinquished his appointment at Cologne and, during the six years 1827–1833, retired into private life.

His desire for freedom to continue his investigations, his annoyance at the delay in obtaining an appropriate appointment, his irritation at being attacked where he ought to have been supported, explain his action at this juncture; but behind it all there was a common cause. His philosophy, that of arriving at the truth by observation and measurement, clashed with what was then being taught at Bamberg, Jena, Heidelberg, and Berlin. Germany was suffering from bureaucracy tempered by despotism, impressed upon the wreckage of an empire that had been restrained from advance by feudal forms and various animosities. Hegel had arisen to teach that human life is of more consequence than its incidents, destiny was again to be the rule, details were nothing, specialism was to be discouraged, the national conscience was to arise and unify the scattered states into an imperial organisation, rising above the finite to the infinite. Hegel had been concerned in the establishment of the *Jahrbücher für wissenschaftliche Kritik*, and in 1827 the popularity of Hegel, expressed in poetry, medals and gifts of silver mugs, was at its zenith. Hartmann, therefore, discloses the truth when he says

> "Die Hegelsche Philosophie beherrschte zu jener zeit das Feld. Sie wollte die Naturgesetze auf dem bequemen Wege der souveränen Spekulation, nicht auf dem mühevollen Pfade der Messung und Beobachtung ergründen. Das war nun freilich nicht nach Ohms geschmack; er war aus einem andern Holtz geschnitzt."
>
> [At that time Hegel's philosophy predominated. It sought to prove the laws of nature, not by the irksome means of testing and observation, but by the convenient method of sovereign speculation. This of course, was not to Ohm's taste; he was of different calibre.

Apart from these initial skirmishes, Ohm's law was for some years scarcely noticed, except by a few physicists. In France, between the years 1831 and 1837, Pouillet demonstrated its truth by direct experiment so effectively, and concentrated his mind upon it so intently, that ultimately he almost thought he had discovered it. The triumph of Ohm came in 1841, when the Council of the Royal Society of London awarded him the Copley Medal for his researches into the laws of electric currents, contained in

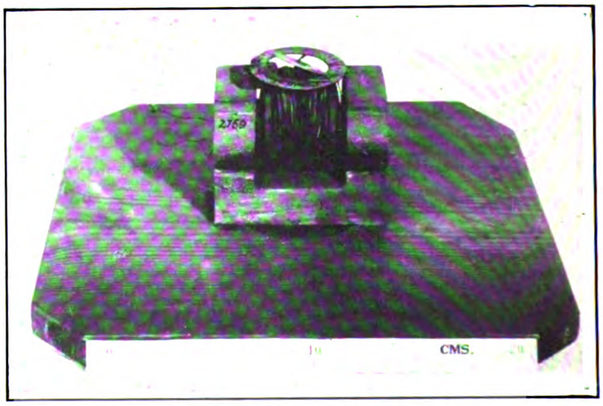


Figure 7—Relic of Ohm's Apparatus. A primitive galvanometer.

various memoirs in Schweigger's Journal, Poggendorff's Annalen, and also in *Die Galvanische Kette Mathematisch Bearbitet.* The Council declared that in these works Ohm had established, for the first time, the laws of the electric circuit a subject then of vast importance, and previously involved in the greatest uncertainty.

Ohm, the Council pointed out, had demonstrated that the usual vague distinctions between intensity and quantity have no foundation, and that all explanations derived from these distinctions are utterly erroneous. Both theoretically and experimentally, Ohm had proved that the action of a circuit is equal to the sum of the electromotive forces divided by the sum of the resistances, and that whatever might be the nature of the current, whether voltaic or thermo-electric, if this quotient be equal, the effect is the same. To Ohm also the Council assigned credit for providing means to determine with accuracy the values of the separate resistances and electro-motive forces in a circuit. They drew attention, moreover, to the extent to which the labours of Ohm had been neglected. Within the five years preceding the bestowal of the medal, however, Gauss, Jacobi, Poggendorff, Henry, and many other eminent philosophers had acknowledged the great value of Ohm's researches and their obligations to him in conducting their own researches. The special subjects noticed by the Council on this occasion were his researches on the conductivity of metals, on the power of electro-magnetic multipliers (galvanometers), and on the nature of unipolar conductors and hydro-electric currents.

In England, those physicists who had most experience in electrical researches bore the strongest testimony to the help they had derived from Ohm's results. It was confessed that if the works of Ohm had been earlier studied, the industry of experimenters would have been better rewarded.

The comment of Eugen Lommel upon this acknowledgment of Ohm's results was:

> "So Wurde Ohm vom Auslande her die späte Anerkennung zu Theil, die ihm das Vaterland so lange vorenthalten hatte."
>
> [Thus foreign countries accorded to Ohm the recognition the fatherland had so long with held.]

Lommel proceeds to state that after the publication of the work on the galvanic circuit, Ohm's attention was directed to molecular physics.

The eulogy bestowed by the Royal Society upon his discoveries, encouraged him to investigate, by the aid of analytical mechanics, the form, magnitude and mode of operation of atoms. He wished, in fact, to produce a *Principia* for the microcosmos. Fate, however, stood between this desire and its realisation. The dismal years 1827–1833 were given by him to mathematical instruction at the Military School at Berlin. He tried unsuccessfully to obtain a better appointment there or at Oldenburg; for the remuneration was less than half what he had received at Cologne. Happily, on July 3, 1833, King Ludwig I, of Bavaria, issued a decree that relieved Ohm of these anxieties. He was given a professorship at the Polytechnic School of Nuremberg, and he retained touch with that institution until 1849. In 1835 he was appointed also to the Chair of Higher Mathematics at the University of Erlangen, and at the same time State Inspector of Scientific Education. Ultimately, he became Rektor at Nuremberg. Towards the end of 1849, he was appointed by

Proſpect der Ritter-Academiæ, des Seminarii und der Evangeliſchen, Teutſchen (St. Sophien) Kirch; Alles erbauet expenſis Lib. Baronis Groſii

Figure 8—University Buildings and Hauptstrasse, Erlangen, 1743–1826.

Maximilian II, Professor of Physics to the University at Munich; the Akademie of Science selected him as Conservator in Mathematical Physics, and in addition, following Steinheil, he was adviser concerning the development of telegraphy for the State. These manifold duties prevented him from continuing his researches in molecular physics. His biographers have found some compensation for this loss in the circumstance that in 1852 and 1853 he published at Munich his results, obtained in the summer of 1851, on interference phenomena and polarised light, and that he discovered how to express his conclusion in a simple formula. Unfortunately, these results, in which two plates of crystal in polarised light could be made to produce a series of concentric coloured ellipses, resembled in many respects those arrived at, quite independently, by Langberg of Christiania, and published in the Norwegian "Magazin for Naturvidenskaberne" for 1841.

Notwithstanding his disinclination for teaching, circumstances to the end obliged Ohm to teach, and he taught well. He was an advocate for individual instruction. The usual two-hour "lecture" was broken up by him; about half was at the black-board, and the remainder was given to working out examples with his students. In this manner he remained in touch with his class. Throughout Germany, his method left its effect. The conditions, however, under which he taught were opposed to rapid progress. For example, students had forms to sit upon, but no desks at which to write. Their mathematical knowledge at entry was so slight that physics to them was at first unintelligible. He realised this, and in 1852 he devoted his precious time to writing out for them with his own hand complete notes, which were lithographed.

Ohm lived simply. He was of marked energy, of middle height, compactly built, sturdy and strong. He was clean shaven, and his friend Mann says tha this physiognomy was of the Martin Luther type. His eyes were large and penetrating; his mouth revealed wit, satire and good humour. The long dark-blue coat he wore was provided with side-pockets which always held a snuff-box. In diction and phrase he excelled; moreover, his voice was full, and far into his life it retained its attractive quality. If a problem was to be solved, he approached it with his students as though he did not yet know what it would reveal. He encouraged them to find the answer, and at last he would ask: Do you understand? Is it clear? After he had explained it, it was always clear, crystal clear. Bauernfeind has recorded that Ohm was by nature benevolent. The bitterness of his early rebuff did not rankle. He spoke but little, but what he said was of substance. Beyond the College gates, he was known within his own country but slightly.

His scientific writings were brought together and published at Leipzig in 1892—under the editorship of Dr. Eugene Lommel, Professor of Physics at the University of Munich—with the title "Gesammelte Abhandlungen von G. S. Ohm." It is a book of 855 pages, relating to 23 communications in which can be seen the results of researches extending over thirty years. The subjects dealt with are comparatively few, but the treatment is thorough, and there is evidence line upon line of tenacity of purpose. From the first, there is manifest the determination of Ohm to establish the law of flow of electricity in metallic conductors. This led him naturally to consider the development of such measuring instruments as the multiplier, or galvanometer, which Poggendorff and Schweigger had devised in 1821. It attracted him also to the results obtained by the English physicists, Children and Davy, with regard to the glow of wires heated by electric currents. Ohm further investigated the question whether the law established for metallic conductors was applicable to liquid conductors. In addition, time was occupied in elucidating the experiments of Ermann on so-called "unipolar conductors." Then followed his work in acoustics, particularly with reference to combination tones, and lastly his experiments and theory relating to polarised light.

From these contributions of Ohm to natural science may be singled out three of transcendent value: his law of electric flow, his law of combination tones, his philosophy of research in physics. The law of electric flow is based upon experimental results appertaining to a property of matter. It implies that the potential difference between any two fixed points on a given homogeneous conductor, when the flow of electricity between those points is steady, is a direct measure of the current in the conductor, between those points. The ratio of that potential difference to that current, in these circumstances, is a characteristic of the portion of the conductor in question, and is called the "resistance." So long as Ohm's law applied, "resistance" thus defined is constant for all values of the potential difference between the two points. In his own words:

> "Die Grösse des Stromes in einer galvanischen Kette ist der Summe aller Spannungen direkt, und der ganzen reducirten Länge der Kette umgekehrt proportional, wobei man sich erinnern muss, dass jetz unter reducirter Länge die Summe aller Quotienten verstanden wird, die aus den zu homogenen Theilen gehörigen wirklichen Längen und dem Produkte der entsprechen Leitungs-vermögen und Querschnitte gebilder werden."
>
> [The magnitude of the current in a galvanic circuit is directly proportional to the sum of all the electromotive forces, and inversely proportional to the whole of the reduced length of the circuit, and it must be remembered that by reduced length is to be understood the sum of all the quotients which can be formed corresponding to all the actuall engths of the homogeneous parts and the products of the corresponding conductivities and cross-sections.]

The law is most easily demonstrated to hold in the case of homogeneous metallic conductors at constant temperature.

Ohm's law thus defined is applicable to all conducting systems and is free from ambiguity; its usefulness has carried it into the wider field of electrical research and engineering, where its interpretation has occasionally been stretched to the very limits of its validity. From metallic conductors it has been extended to electrolytes, from electrolytes to dielectrics, from dielectrics to electric arcs, and from arcs to thermionic valves. Moreover, by mathematical devices, inductance, capacity, and leakance have all been operated upon to convert them into terms capable of being interpreted as "resistance," so as to bring them under the jurisdiction of a kind of Ohm's law. A clash consequent upon this struggle for latitude occurred in England in the summer of 1896, when there was a fierce and prolonged debate with regard to the existence, or not, of "negative resistance" in the electric arc. The attack was led by Dr. S. P. Thompson, at a meeting of the Physical Society of London, and was hotly responded to by Professor W. E. Ayrton, in a characteristic speech beginning with the words "It is a pity that so much erudition should be marred by three obvious misconceptions. . . ." After some weeks of acid controversy, it was decided to refer the matter for settlement to Oliver Heaviside who gave judgment as follows:

> "I am asked my opinion about negative resistance. This I take to mean simply that if a body formally obeyed Ohm's law, $E = RC$, and Joule's law, $H = RC^2t$, but with R a negative instead of a positive quantity, it would possess negative resistance. The effects produced by the negativity of R (and other quantities) have occupied my attention in certain papers, and are interesting and instructive. But I have no faith whatever in the permanent existence of a body with negative resistance, on account of the general instability. At the same time I am not prepared to deny that a substance might temporarily, and under suitable circumstances, behave as a negative resistance approximately, especially if it is in a state of continuous material change. . . . Whether the arc may be conveniently regarded in this light, is not for me to say. I do not know enough about the arc. I prefer gas for personal use."—*Oliver Heaviside*, July 28, 1896.

Pioneer work in electrical communication, from the middle to the end of the nineteenth century, was in great measure carried on by electricians whose equipment of theory was limited to applications of Ohm's law in the somewhat ambiguous form

$$\text{Current} = C = \frac{E}{R} = \frac{\text{Electromotive-force of battery}}{\text{Resistance}}.$$

When they dealt with single metallic conductors, there was not much difficulty. The application of the formula to networks, and to circuits containing electrolytes, especially if so-called "back Electromotive forces" happened to be present, was sometimes troublesome to them. The meaning of the difference of potential between two points was clear, because most of the electricians of that time were familiar with static electricity, and with some form of electrometer. They had, however, to grasp the fact that in applying Ohm's law they were concerned not merely with the electromotive-force of their battery, but with electrolytic and other effects, usually involving a counter electromotive force E_1, so that the current was given by

$$C = \frac{E - E_1}{R},$$

where R was known or could easily be measured. With the improvement of galvanometers, there followed the ammeter and the voltmeter. Electricians began to think less in terms of resistances, and more in terms of current and fall of potential along conductors. At the next stage of the advance, attention was directed to concise definitions of electrical power and electrical energy. Ohm's law remained the basis, and carried its way at last into the new field of alternating current theory. This had been forbidden ground, for Ohm's law predicated the steady state, and here all that was constant was inconsistency. Nevertheless, a variety of Ohm's law at last sprang into existence for alternating currents, and it flourished exceedingly. Thus Ohm's law was—as Ohm had prophesied in *Schweigger's Journal* of 1826, it would be—in perfect agreement with experiments in all directions, and characterised by simplicity that extends its application to all experience with electric currents—simplicity such as is only found in truth. Or in his own words:

> ". . . wie nur in Gefolge der Wahrheit zu erblicken ist, als das reine Gesetz der Natur verkündigt."
> [Revealed only in the quest of Truth, as manifested in the pure law of Nature.]

He started from the fact that when two dissimilar metals, or certain other substances, touch one another, they maintain at the point of contact a difference of potential. He recognised that chemical changes in fluid portions of a circuit introduce complexities that occasionally lead to apparent exceptions. These, until interpreted, amount almost to contradictions. He therefore deferred consideration of the parts of circuits that are subject to chemical change, and he dealt first with a circuit of homogeneous material of the same cross-section throughout. For such a circuit he found by experiment that the slope representing potential, coordinated against electrical resistance, is a straight line. This line he plotted, and he proceeded in like manner to obtain zig-zag representations of the fall of potential for composite circuits built up of conductors of various lengths, sections, and materials. Then he showed how to calculate the fall between any two given points along such a composite circuit. He demonstrated that for the steady state, or in his words, for a circuit—"deren Zustand bleibend ist"—the current is of equal strength at all points along the conducting system, and that a change of current at any one point corresponds to similar change of current throughout. He stated his law, in terms not of "resistance" but of "reduced length." By "reduced length" he meant the length of a wire—of given material, such as standard copper, and of given sectional area—having a resistance equal to the sum of the resistances of the circuit in question.

He pointed out that this law differed essentially from those of Davy, of Becquerel, of Barlow, and of his own early investigations; the discrepancies in those tentative formulae he attributed to the smallness of the range available in the interpolations by which they had been obtained. His argument was next directed to proving that interchange of the parts of a composite line of conductors has no effect upon the total resistance. He proved that for all points along the conductor, provided that the ratio of potential difference to resistance is constant, the current is constant. The trouble in his experiments arose because the resistance of his battery was large and unsteady. He explained why results of greater consistency were obtained with a thermocouple, where the resistance is small. Then he dealt with problems relating to cells in series and in parallel, the effect of putting a galvanometer into the circuit, and general expressions for the resistance of conductors in parallel. He studied also what happens when a conducting body of considerable size is brought up to a circuit, and he showed that the effect is independent of the material of the added body provided that it is a conductor. He completed the task by mathematical investigation of the current in a circuit when the atmosphere exerts some effect (i) without chemical changes, and (ii) with chemical changes. In this part of his work he led the way to the problem of leakage of transmission lines, and its solution by hyperbolic functions in exponential form.

To convert what at first was an empirical rule, into a physical law of the highest order, it was necessary for Ohm to give it the support of theory. He proceeded to develop a theory of electric flow, following the results of Laplace, of Poisson, and chiefly of Fourier with regard to the diffusion of heat. During the years 1807–1816, Joseph Fourier had communicated several important contributions upon diffusion to the Institut de France. In 1822 there was published his Théorie Analytique de la Chaleur—which Heaviside in 1895 described as the most entertaining mathematical work ever seen. Its appearance was well timed to influence Ohm. Fourier began with the observation that different bodies possess in different degrees the power (i) To contain heat; (ii) To conduct heat through their substance; (iii) To receive or to transmit heat through their surfaces. Corresponding thereto he defined (*a*) The capacity (la capacité de chaleur); (*b*) Specific conductivity (la conducibilité propre); (*c*) Emission conductivity (la conducibilité exterieure).

Fourier had found that when a metal bar is exposed at one end to the constant action of a source of heat, and every point of the bar has attained its highest temperature, the system of fixed temperatures is distributed along the bar in accordance with a logarithmic law. His next step was a statement to the effect that the slope of any curve at a given point measures in geometry the tangent, in dynamics the velocity, in heat the quantity that flows at each point of a body across a given surface, in a small unit of time. He further laid it down that the quantity of heat that one molecule receives from another in a given time is proportional to the difference of temperature of the two molecules, and he derived, for the temperature at any given point along the bar, an equation of the exponential form that in recent years has become familiar in the corresponding problem of electrical transmission, where attenuation is taken into account.

Ohm assumed that the three constants and the mode of handling the differential equations that had been used by Fourier and by Poisson in the heat problem would be directly applicable to electrical conduction. He therefore introduced corresponding coefficients, and he wrote down the differential equation connecting the rate of change of potential with time at any point along an electrical conductor, in terms of the potential itself and of the second differential of potential in respect to distance. The current was next expressed as the rate of change of potential with distance, multiplied by a coefficient; and he showed that since there can be no heaping up of electricity at a point, such an expression with appropriate coefficients can be applied to composite conductors, or to branched circuits. Further, a branch might be a liquid, provided that there is a good contact at the surface of separation. His first differential equation was subsequently made to represent the steady state by omitting the time term; the integration was thus simplified, and he obtained an expression for the potential at any given point along the conductor—the law of electrical diffusion, where the diffusion occupies the entire conductor. He considered also what happens when such a conductor is left to itself, and further the effect of bringing into contact with it, at a given point, a mass of metal or other conducting substance.

Maxwell (Art. 333, "Electricity and Magnetism") paid full tribute to the excellence of this work of Ohm, but he held that Ohm, misled by the analogy between electricity and heat, entertained the erroneous opinion that a body when raised to a high potential becomes electrified throughout its substance, as if electricity were compressed into it. Maxwell pointed out that although this opinion itself was wrong, it led Ohm to employ the Fourier equations to express the true laws of conduction of electricity through a long wire. In these circumstances it is desirable here to record the original statement of Ohm (p. 145, *Gesammelte Abhandlungen*):

"Es ist nämlick durch theoretische Betrachtungen sowohl als auch durch Versuche, welche an dem elektrischen Strome angestellt worden sind, keinem Zweifel mehr unterworfen, dass die bewegte Elektricität in das Innere der Körper dringt, und ihre Menge sich deshalb nach dem Körperlichen Raume richtet, während es auf der anderen Seite ebenso ausgemacht ist, dass die ruhende Elektricität an der Oberfläche der Körper sich sammelt und ihre Menge deswegen von der Flächengrösse abhängig ist."

[From theoretical considerations and by experiments with electric currents, there is left no further doubt that electricity in motion penetrates the interior of bodies, and that consequently the quantity depends upon the volume of the bodies. On the other hand, it is found that the static electricity on the surface of the bodies accumulates and that its quantity on this account depends upon the extent of the surface.]

It must be remembered that Ohm's task was to bridge the gulf between static charge and the steady state of electric flow. He had to contend with the fact that whereas a static charge resides only on the surface of a conductor, electricity in motion through a wire, for the steady state, utilises not merely the surface but the whole cross-section and substance of the wire. Was he then in error in the manner suggested by Maxwell? The essential distinction that Maxwell wished to emphasize was no doubt that to which he directs attention in Art. 244 of "Electricity and Magnetism." In the electrical case, however powerfully a closed conductor may be charged, there are no signs of electrification within it; and an insulated body within it will, when taken out, exhibit no electrical effects. In the thermal case, if such a conductor is raised to a high temperature, the body within it will, after a considerable time, rise to about the same temperature as the conductor itself, and when it is taken out it will be hot. Conducting bodies can absorb and emit heat, but they can neither absorb nor emit electricity. Hence, in electrical phenomena there is complete absence of anything to correspond to capacity for heat, or in Maxwell's words:

> "It is impossible to give a bodily charge of electricity to any substance by forcing an additional quantity of electricity into it."

If Ohm had lived to reply to Maxwell he would have responded—"I never said you could." He should be credited with having used the analogue to Fourier's *capacité de chaleur* with mental reservations.

Heaviside, who otherwise appreciated the work of Ohm, re-echoed the complaint that the assumption that a wire possesses the power of storing up electricity in its substance, like heat, is erroneous. In partial vindication of Ohm, however, he added:

> "Why he should have come to the right result by wrong method was simply that, whether electricity is stored up in the substance of a wire, or goes to the surface and stays there, the equations are of exactly the same form."

In the interpretation of Ohm's law by analogies, Heaviside also warned electricians against supposing that electromotive force has to "overcome" resistance, as though resistance were a force of friction. In the sense in which resistance is spoken of in association with Ohm's law, the mechanical analogue of resistance is more closely that of a coefficient of velocity in the case of a body, on a level surface, sliding steadily under the action of a constant force. The constant force (electromotive-force) is represented by the product of the velocity (current) and the coefficient (resistance), there being in this analogy no lifting of the load.

Contemplation of the physical contrasts that manifest themselves in the study of the way in which Ohm's law is established—the distinctions between heat and electricity, mechanical friction and electrical resistance, the residence of static charges of electricity at surfaces and the fact that electrical resistance to steady currents is a function of the whole cross-section, added to the part played by magnetic forces, and the mystery in all these circumstances of how an electric current heats a conductor—thus reveals to us how wide are the gaps yet to be filled between the conventional framework of hypothesis that serves so well as a base for calculation within the present range of electrical knowledge, and the real machinery and scheme of operation of conductance.

The work of Ohm upon so-called "unipolar" substances deserves attention. It relates to experiments by Jäger, Becquerel, Fechner, Ermann, and others, with metallic plates and condensers, particularly with regard to the effect of earth connections and residual charges, and to a group of partial conductors, containing disturbing electromotive forces. It was concerning such results that Biot said that in no branch of physics were there so many differences of opinion and uncertainties of those relating to *galvanismus*, and that there was (1831) scarcely a physicist whose views did not differ from those of every other upon important principles. Becquerel, Davy, Walker, Ritter, Berzelius, de la Rive, and Nobili, were all conspicuous in this heterodoxy. Ohm saw that much of the trouble arose from defective instruments. He realised that the galvanometer as then constructed did not answer the "Wo und Wie" as he called it.

Thereupon he directed attention to the merits of the electrometer that deals with only single points of a circuit, and he advocated the simultaneous use of both instruments, particularly in circuits containing metals and liquids.

Attention became more or less focussed upon an experiment by Ermann. He claimed to have discovered a class of imperfect conductors capable of transmitting more easily one of the electricities than the other. For example, into a piece of soap, alkaline and very dry, he introduced two metallic wires each communicating, respectively, with the poles of a battery. The two poles retained their potentials. But, on touching the soap with a conducting body, the negative pole became discharged, and the positive pole acquired the potential it possessed when the soap was removed and the negative pole was put to earth. He found the same result with the dried white of an egg, with the flame of phosphorus, the flame of alcohol, and with other flames, except that it was the positive pole that became discharged in flames. For this reason he introduced the terms "unipolar-negative" and "unipolar-positive."

Ohm interpreted the results as a property not of the substance interposed between the poles, but of the current that traverses the substance, *i.e.*, as an electrolytic effect. The soap, in his opinion, was decomposed into an acid and into an alkali. The acid he thought to be of an insulating character, and the acid, he supposed, enveloped the positive wire, preventing the positive charge from passing to earth.

The literature of this and allied subjects throughout Europe, for various reasons, covers an extended period. Ohm's book "Die Galvanische Kette" was translated into English in 1841, and into Italian in 1847; Pouillet supplied a translation of part of it in 1837, but it was not available in complete form in French until 1860, when J. M. Gaugain produced an edition with appreciative critical notes. By 1860 it was widely known that Ohm had discovered what was generally called the law of length, section, and derived circuits, but it was not then generally recognised that this law was associated with a theory that embraced innumerable questions relating to the propagation of electricity.

In 1838 *Faraday* (*Experimental Researches, Vol. 1, No. 1635*) discussed unipolar bodies. He remarks:

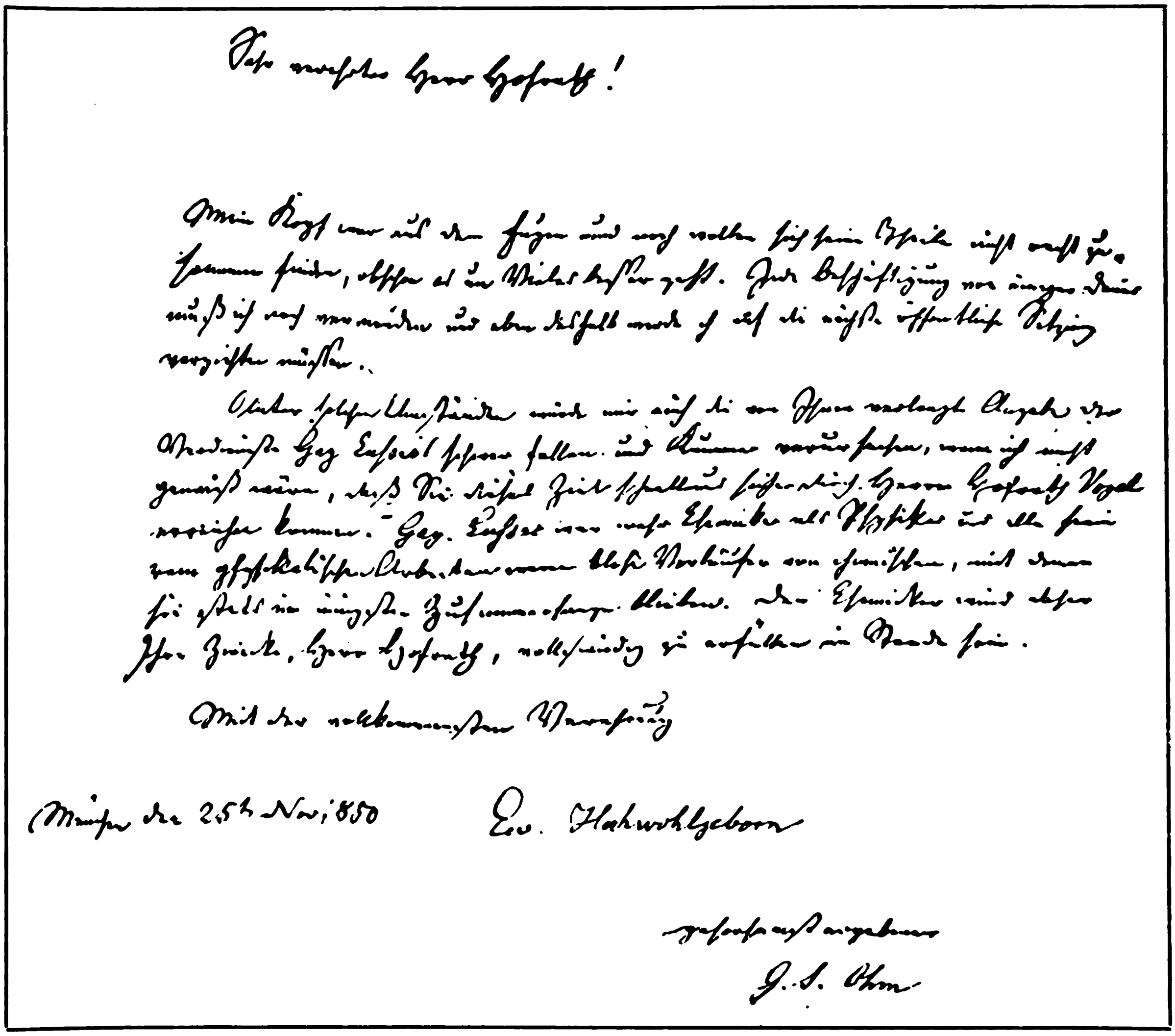
> "If a unipolar body could exist, i.e., one that could conduct the one electricity and not the other, what very new characters we should have a right to expect in the currents of single electricities passing through them, and how greatly they ought to differ, not only from the common current which is supposed to have both electricities travelling in opposite directions in equal amounts at the same time, but from each other! The facts which are excellent, have, however, gradually been more correctly explained by Becquerel, Andrews and others, and I understand that Professor Ohm has perfected the work, in his close examination of all the phenomena; and after showing that similar phenomena can take place with good conductors, proves that with soap, etc., many of the effects are the mere consequences of the bodies evolved by electrolytic action."

Ohm's researches on this question had appeared in *Schweigger's Jahrbuck der Chemie, Vol. 8, 1830*, and it is in relation to this that Faraday added:

> "Not understanding German, it is with extreme regret I confess I have not access, and cannot do justice, to the many most valuable papers in experimental electricity published in that language."

Ohm's contributions to acoustics appeared in Poggendorff's Annalen in the years 1839–1843. His researches led to the establishment of his law governing combination tones—by which the human ear proceeds in its analysis.

He showed that the ear can derive the sensation of tone only from that particular motion of the air in which the particles oscillate like a pendulum. Helmholtz summarized the results by stating that every motion of the air that corresponds to a composite assemblage of musical tones is, according to Ohm's acoustic law, capable of being analysed into a sum of simple pendular vibrations, and to each such single simple vibration corresponds a simple tone, sensible to the ear, and having a pitch determined by the periodic time of the corresponding motion of the air. This law rescued acoustics from confusion. Its effect in the development of innumerable applications of physical science is everywhere to be observed. Yet it remained in comparative oblivion for eight years after the death of Ohm, i.e., until Helmholtz in



Sehr verehrter Herr Hofrath!

Mit der vollkommensten Verehrung

München den 25t Nov. 1850

Ew. Hochwohlgeboren

gehorsamst ergebener
G. S. Ohm

Figure 9—Handwriting of G. S. Ohm.

TRANSLATION

To Councillor von Thiersch,—

My head was in a whirl and is still not quite clear, although it feels much better. I must avoid all continuous occupation, and for this reason I shall not be able to attend the next public conference.

Under these conditions, the information you requested, relating to the merits of Gay Lussac would be difficult for me to give—this would cause me distress if I were not certain that you could obtain what is required, rapidly and surely through Councillor Vogel.

Gay Lussac was more of a chemist than a physicist, and all his purely physical work was merely a forerunner of the chemical, to which it always remained most closely related. A chemist will therefore be in a position to fulfil your request completely.

Yours,
G. S. Ohm.

Munich, 25th November, 1850.

"Die Lehre von den Tonempfindungen" used it to explain the relation of overtones to music. This achievement of Ohm is enhanced by the fact that he possessed no ear for music. Urged by a strong desire to solve the riddle of musical tone, he enlisted the services of a musical friend to supply an ear, and he found this friend in Dr. Kellermann.

Ohm's work was based upon the principle that the truth of what is demonstrated by experiment cannot be denied, that what is based upon hypothesis must only be accepted in so far as it is confirmed by observation, that until theory can be exhibited as precise calculations it is imperfect and does not inspire confidence, and that such calculations are the touchstone of hypothesis. His precept was that where these tests are lacking it is best to defer judgment until better data are available. He studied especially conductivity because he imagined that it would lead to knowledge of the internal structure of matter. Bauernfeind states that Ohm's view was that the attractions and repulsions of magnets should be explained not by supposing the existence of positive and negative magnetism, but by imagining in the atoms (Körperatome) the existence of constant positive and negative currents.

At 10 p.m. on July 6, 1854, on which day, notwithstanding his bodily weakness, he had delivered his lecture, Ohm died. On the following Sunday he was buried at Munich. The grave is in the Sudliche Friedhof which can be reached from the city by way of Sundlingertor Platz and Thalkirchner Strasse. It is near the edge of a path that skirts the front of a building known as the Akadien, within the cemetery. Following that path, the grave is about twenty-three paces from the eastern extremity of the building. It is overgrown with ivy, but the simple stone stands clear, and is inscribed:

Hier ruht
GEORG SIMON OHM
KGL. PROFESSOR
an der Universität
in München
Geb. 16 Marz 1787
Gest. 7 Juli 1854

[Here lies
Georg Simon Ohm
Professor
at the University
of Munich
Born 16th March, 1787
Died 7th July, 1854.]

It is unfortunate that a philosopher who devoted his life to precision should have inaccuracy stamped upon what is alleged to be his house, and an erroneous date engraved upon his tombstone. He was born not in 1787 but in 1789.

In 1881, The Electrical Congress at Paris adopted the name of Ohm for the practical unit of electrical resistance, 1 Ohm = 10^9 C.G.S. units. The standard Ohm is now determined with an accuracy of about 1 part in 100,000.

As an example of his handwriting, the letter (Figure 9) reproduced from Ludwig Hartmann's book may be examined. It relates to a request made to Ohm by Thiersch for an obituary notice of Gay-Lussac, who died on May 9, 1850.

Broadcasting in Sweden, Norway and Denmark

By A. TARANGER

Standard Electric Aktieselskap

THE development of electrical communication always has had strong support from the three Scandinavian countries, Sweden, Norway and Denmark. Many of those who aided in its realisation were born within their boundaries, and the present high standard of telephone communication in Scandinavia proves that those responsible for its present progress are keeping in close touch with new inventions and designs that may improve its usefulness.

When broadcasting first appeared on the western horizon on its way from America via England to Europe, its application to Scandinavian conditions was immediately studied by the respective telegraph administrations. Its importance for intelligence communication was evident to all concerned, and it was realised also that the Scandinavian countries would have greater difficulties than the majority of other countries in establishing an efficient broadcasting service—for the lower the density of population, the more insecure is the economical basis for a broadcasting service.

The following data represent the position in this respect:

	Population	Area in km²	Number of people per km²
Sweden.........	6,040,000	448,000	13.6
Norway........	2,750,000	323,800	8.5
Denmark.......	3,390,000	43,000	79.0
England........	45,000,000	244,000	184.0

From these figures it is apparent that Scandinavian countries, especially Sweden and Norway, when compared with England, have greater difficulties in establishing an effective broadcasting service able to support itself economically.

The small density of the population was, however, not the only difficulty that presented itself to the Scandinavian Administrations. In Sweden and Norway, the geographical conditions were highly unfavourable to the distribution of electromagnetic waves. To appreciate this fact, it is only necessary to point out that the whole interior of Norway consists almost exclusively of a mountainous plateau with slopes covered by forests. In Sweden the same conditions are found, though less pronounced. The consequence is that the population is distributed throughout a narrow strip round the coast. From the map, Figure 1, showing the density of population and its distribution, the difficulties which arise are evident.

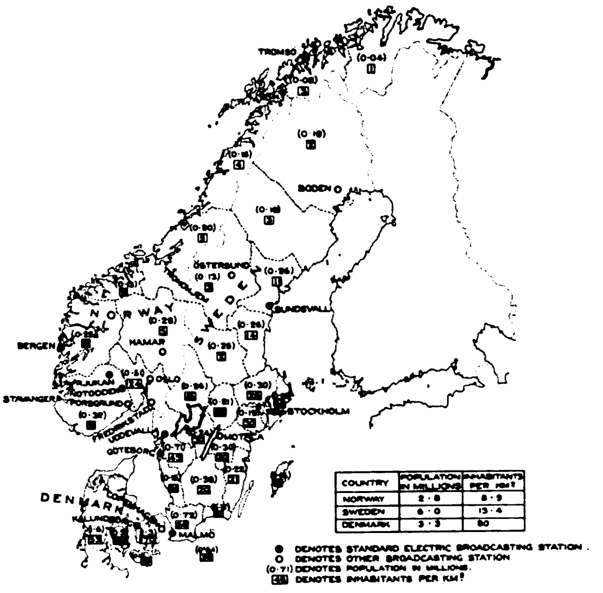

TROMSØ
BODEN
ÖSTERSUND
SUNDSVALL
NORWAY
HAMAR
BERGEN
OSLO
STAVANGER
STOCKHOLM
GÖTEBORG
DENMARK
MALMÖ
COUNTRY | POPULATION IN MILLIONS | INHABITANTS PER KM²
NORWAY | 2·8 | 8·9
SWEDEN | 6·0 | 13·4
DENMARK | 3·3 | 80
● DENOTES STANDARD ELECTRIC BROADCASTING STATION.
○ DENOTES OTHER BROADCASTING STATION
(0·71) DENOTES POPULATION IN MILLIONS.
▭ DENOTES INHABITANTS PER KM²

Figure 1—Map Showing Density and Distribution of Population Throughout Scandinavia.

In Denmark, conditions are much more favourable for the transmission of the electromagnetic waves, and also from the standpoint of density of population. The fact, however, that the main supply of programmes must be distributed from Copenhagen, on the island Sjaelland, makes it difficult to arrange simultaneous broadcasting over relay stations for the reason that the submarine cables connecting the island with the peninsula Jylland are not suitable for transmitting music.

Sweden

The development of the Swedish broadcasting service is one of the most interesting chapters in the short but important history of broadcasting. Taking into account its area, and the population living within its boundaries, Sweden must be regarded as having solved the question of establishing a public broadcasting service in a remarkably satisfactory way. Broadcasting started there in the fall of the year 1923, with one small 500-watt station, Western Electric type 1-A; during 1926, as many as 27 stations, involving the use of 6,000 km. of open wire line for simultaneous broadcasting purposes, were in operation. The total number of paid receiving licenses on March 15, 1927, was 265,000, or 44 per thousand of population. The fee is 10 kronor[1] per year, payable in January of each year.

The service exists through the cooperative efforts of the Swedish Government and a private programme service company called A/B Radiotjänst. The Swedish Government purchased all the main stations and all the technical equipment necessary for the simultaneous broadcasting of the programme through all stations. The main stations are Stockholm, Göteborg, Malmö, Sundsvall, Boden, Östersund and Motala. The latter, a high power broadcaster of 30 KW antenna energy, has replaced the station at Karlsborg. The Swedish Government operates all these stations, and supplies the technical apparatus and the operators needed to broadcast any important outside events at any place in Sweden.

The programme service Company supplies all the programmes, and operates studios in all towns having main stations. A local programme board is established in connection with all studios outside of Stockholm. These local boards have considerable power to decide the local programmes for each town, and often they have the opportunity to transmit All-Swedish programmes, viz., programmes simultaneously broadcast by all stations. It is claimed that the service in Sweden is so flexible that in 10 seconds all stations can be switched over from one studio to any other in that country. The headquarters of the programme service are in Stockholm, and from the studio located there, the main part of the programmes are transmitted.

To supervise the expenses involved, and to provide interest on the invested capital, the programme service board receives one half, viz., 5 kronors, of the license fee. Amounts left over at the end of each year are returned to the Swedish Government coffers.

In order to control the expenditures as well as to aid in regulating the programme, one representative of the Telegraph Administration is on the Board of Directors of the programme service Company, and two representatives are on the Board of Programmes.

Aside from the seven main stations, twenty smaller relay stations are now in operation. Inasmuch as the Swedish Government obviously could not at once build a complete net of broadcasters to meet the demand of the whole country satisfactorily, temporary licenses were granted to radio clubs in towns outside the service areas of the main stations. Each of these local stations has been allotted a small service area corresponding to their antenna energy. For those who attain a total number of a thousand or more listeners, the Government pays over to the club 2 Swedish kronors per license belonging to that service area. Some of the larger local broadcasters are now operated by technical men from the radio department, who also have taken over the running expenses. These broadcasters are the so-called "desired" broadcasters, viz., stations serving large communities not expected to be included in the service area of the main broadcasters in the near future.

As will be seen from the above, the Swedish operating organization consists of two distinct parts; viz., the Government, and the programme service Company. The Government also exercise control of the service on behalf of the public. The reasons why the Government have taken an active part in the operation side of the service are as follows:

The Government have available in the radio department of the telegraph department, executives, engineers and operators trained in the installation and operation of radio transmitting apparatus; and further, it was estimated originally that the revenue that would be obtained from listeners would not be sufficient to make it possible for a privately financed concern to erect an adequate number of stations of satisfactory power output to serve areas not comparatively densely populated. Moreover, the fact that the Government toll line service was involved, made it important that the technical side of the service should be dealt with by the Telegraph Administration.

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[1] One English £ sterling is equivalent to 18.16 Swedish kronor, nearly.

Norway

As early as the spring of 1923, a 500-watt broadcasting station that had been lent to the Norwegian Telegraph and Telephone Administration by the Western Electric Norsk Aktieselskap (now Standard Electric Aktieselskap) was installed in Oslo. The Administration required this station in order to become acquainted with the technical problems involved; and it was hoped also to interest the public sufficiently, so that an idea could be obtained of what support a future operating concern might expect.

The preliminary service was stopped during the fall of the same year. Several attempts were made from different sources to obtain a license from the Norwegian Government to start a broadcasting service, but from various causes, none succeeded. Finally a group, consisting of the three large radio concerns and the Press, came to an agreement with the Norwegian Government, and in February, 1925, the first broadcasting company, Oslo Kringkastingselskap, was started, with a fully paid capital of 350,000 Norwegian kroner[2] (about £ 19,100). The public readily purchased the shares.

The important terms of the license were as follows:

The Broadcasting Company was granted a license to operate one or more broadcasters within the area enclosed by a circle of 150 km. radius with Oslo as centre.

The Company was required to purchase the stations needed, but these were to be erected on premises chosen by the Norwegian Government through the agency of the radio department of the Norwegian Telegraph Administration. The stations were to be operated by the radio department, but the cost of services so rendered were to be paid for by the Company.

Each listener, within the service area allotted to the Company, pays a fee of 20 kroner, collected by the Telegraph Administration. For the service, the Administration receives 20 per cent of the total amount of the fees.

Further, a stamp duty is paid on all radio material sold, the duty being collected by all dealers in radio apparatus. The value of the stamps was stipulated to be approximately 10 per cent of the retail value involved.

For the organization of the control service necessary for this stamp duty, and for the collection of the duty from the dealers, the Norwegian Government retains 20 per cent of the total amount. As this stamp duty is also collected on apparatus sold outside the service area of the Company, other broadcasting companies which may be formed for other service areas are given a right to obtain part of this revenue. The division of the revenue is dependent upon the number of listeners registered under each service area. There is one representative of the Norwegian Government on the Board of Directors of the Company.

The license is granted for five years with a right for the Norwegian Government to change the terms of the contract after two years. If the new terms are not agreed upon, the Norwegian Government take over the Company's assets at their book value. The whole plant must be depreciated to no value after five years. At the end of each year, the amount left over of the income of the Company is paid over to the Norwegian Government, with the exception of the payment to the shareholders of 7 per cent on the par value of the stock. Due consideration is given to the necessity for providing funds for future expansion, depreciation of the plant, and losses.

There exist now three operating companies in Norway; viz., Oslo Kringkastingselskap, Bergen Kringkastingselskap, and Troms Kringkasting A/S. The total number of receiving licenses issued is 63,000, of which more than 48,000 belong to the Oslo area; about 11,000 to the Bergen area, and 550 to the Troms area. The rest do not belong to any area.

Two operating companies in Trondhjem and Stavanger are trying to interest local capital, but up to the present, the attempts have not been successful.

There are now eight broadcasters in operation in Norway, of which six belong to the Oslo area, one to the Bergen area, and one to the

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[2] One English £ sterling is equivalent to 18.32 Norwegian kroner, nearly.

Troms area. The operating license is to all intents and purposes alike for the three Companies.

To sum up, it can be said that Norway has adopted a system of several operating concerns to serve the needs of the public under Government control and assistance, but not with financial participation on behalf of the Government.

The difficulty experienced in Norway is mainly that, while Oslo is the most remunerative area, yielding a revenue in excess of what is absolutely needed for a satisfactory service, the Bergen area hardly yields sufficient for the maintenance of good programmes and the running expenses for the stations. Areas with a smaller population will, on the present basis, not yield sufficient income to meet the expenses involved. Naturally the total overhead expenses are larger when three or more companies are established, than when only one company has charge of the whole country. A point in favour of changing the present system is that adequate programmes can only be expected to be obtained from the capital city, Oslo. If these programmes were relayed, a charge would be made to the other broadcasting companies, and in this way the favourable position of the Oslo Company would be further accentuated. On the other hand, when the geographical formation of the country is considered, the consequent spreading of the population along the coast, and the poor state of the toll lines, there are evidently many factors in favour of the establishment of local broadcasting companies.

Denmark

Of the three countries, Denmark was earliest in the field of broadcasting, for the Danish Government station at Lyngby was used partly as a broadcaster towards the end of 1922. Later, through the cooperation of several interested parties, a broadcaster was manufactured and erected in Copenhagen. The radio department of the Telegraph Administration have operated the broadcasting station, and have provided a studio for the use of the programme organization established through the cooperative efforts of radio clubs and dealer associations. Expenses were, in the first instance, covered by a voluntary fee paid by listeners and dealers.

In 1924, however, the Danish Government instituted a compulsory fee for all listeners, but a difference was made between the amounts to be paid by those using crystal sets, and those having valve sets. A definite operating organization was established in 1925.

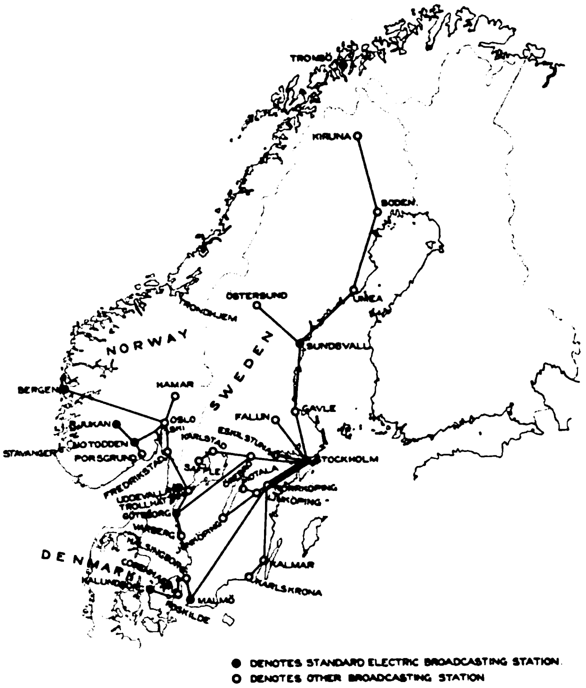

Figure 2—Map Showing Network Used for Simultaneous Broadcast of Scandinavian Programmes.

The Danish Government undertook to erect and operate all broadcasters needed for the country and also agreed to provide the programmes. In order to represent all the interests involved, a supervisory board of thirty-two members was appointed by the Government. This number, however, was too large to be really useful to supervise the extension of the service and the development of the plant and has been reduced to nine. A fee of ten Danish kroner[3] is paid by each listener, the total number of whom is now approaching 150,000.

An active feeling existed among the public that their interests were not sufficiently provided for and, in the spring of 1926, the Danish Government decided to purchase a station of

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[3] One English £ sterling is equivalent to 18.20 Danish kroner, nearly.

7.5 KW antenna energy to serve the whole country and to erect several relay stations in suitable places. The Government installed at Kalundborg, on the island Sjaelland, a 7.5 KW Standard broadcaster, which was placed in service on August 29, 1927. The old Copenhagen station is still working, but is being replaced by a new station now under construction.

The organization chosen by Denmark is completely run by the Danish Government, but the interests of the listeners and the trade have been regarded by incorporating their representatives in a board of control, which in reality is responsible for the broadcast service. The "Radio Council," as the Board of Control is called, is thus an operating concern responsible to and financed by the Danish Government.

The results obtained, as indicated by the number of listeners—approximately 54.8 per thousand on December 31, 1927—show that the system is adequate for the needs of the country, and place Denmark in a position amongst the first broadcasting countries in Europe.

All-Scandinavian Programmes

It is natural that the three countries, Sweden, Norway and Denmark, so closely related geographically, politically, and in the nature of their people and languages, should cooperate to a considerable extent by interchanging programmes and comparing experiences. During recent years, several All-Scandinavian programmes have been transmitted by all broadcasters in Scandinavia, and during the winter season the operas arranged by the Swedish programme Company, Radiotjänst, is a regular feature on the Norwegian programmes.

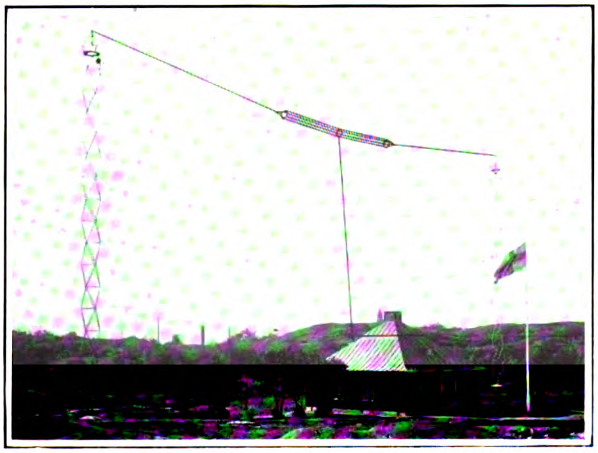

Figure 3—Göteborg (Sweden) Broadcaster.

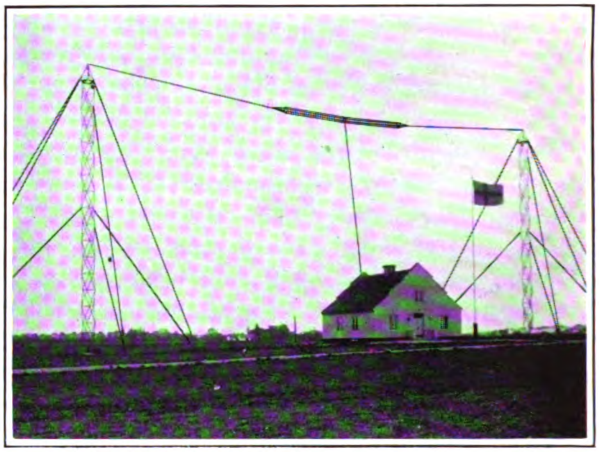

Figure 4—Malmö (Sweden) Broadcaster.

The network used for the simultaneous broadcast of Scandinavian programmes is shown in Figure 2. Relaying musical programmes to Denmark involves technical difficulties arising from the necessity of including a Krarup loaded sea cable between Helsingborg and Helsingör in the line transmission circuit. The frequency-attenuation characteristic of this cable is not satisfactory for the transmission of music, and often it has been found preferable to use the transmission from the Malmö broadcaster as the last link in the circuit between Stockholm and Copenhagen.

The circuit between Stockholm and Oslo involves mainly overhead lines via Göteborg to a small place called Ski, 80 km. outside of Oslo. From there it passes through a special non-loaded pair in the loaded cable Ski-Oslo. This special pair is equalised to give uniform attenuation over the range of frequencies involved in the transmission of music.

As, however, the attenuation of this open wire circuit, approximately 800 km. in length, varies with changes in the leakage resistance, arising from changes in the weather, it is difficult to keep the quality of the All-Scandinavian programme up to the high standard obtained when broadcasting from local studios. Especially in Norway, great difficulties are experienced in keeping the transmission equivalents constant on long open wire circuits, and tests are now being made to determine the feasibility of replacing the wire circuits by short wave radio transmission circuits.

Broadcasting Stations in Daily Operation

The illustrations (Figures 3 and 4) show broadcasters of Western Electric manufacture now in operation in Göteborg and Malmö. The following is a list of all stations now in daily operation in Sweden, Norway and Denmark:

BROADCASTING STATIONS IN DAILY OPERATION

Name of Station	Wave-length	Antenna Power	Owner
Norway			
Hamer......	555.6	1000	Broadcasting Co.
Aalesund....	512	500	Government
Porsgrund...	500	1000	Broadcasting Co.
Tromsö.....	500	150	“ “
Oslo........	461.5	1500	“ “
Rjukan.....	448	250	“ “
Fredrikstad..	434.8	1000	“ “
Notodden...	411	800	“ “
Bergen......	370.4	1500	“ “
Denmark			
Kalundborg .	1153.8	7500	Government
Copenhagen .	337.1	3750	“

BROADCASTING STATIONS IN DAILY OPERATION

Name of Station	Wave-length	Anode KW	Owners and Operators
Sweden			
Boden......	1200	1.00	Government
Borås.......	230.8	0.25	Radio organization
Eskilstuna...	250	0.30	“ “
Falun.......	357.1	—	“ “
Gävle.......	204.1	0.40	“ “
Göteborg....	416.7	1.10	Government
Halmstad....	215.8	0.40	Radio organization
Hälsingborg .	229	0.40	“ “
Hudiksvall ..	272.7	0.25	“ “
Jönköping...	201.3	0.40	“ “
Kalmar.....	254.2	0.40	“ “
Karlskrona ..	196	0.40	“ “
Karlstad....	220.6	0.45	“ “
Kiruna......	238.1	0.50	
Kristinehamn	202.7	0.45	“ “
Malmberget .	400	0.40	
Malmö......	260.9	1.10	Government
Motala......	1380	40.00	“
Norrköping..	275.2	0.40	Radio organization
Stockholm...	454.5	1.50	Government
Sundsvall....	545.6	1.10	“
Säffle.......	252.1	0.60	Radio organization
Trollhättan..	277.8	0.70	“ “
Uddevalla...	294.1	0.12	“ “
Umeå.......	229	0.30	“ “
Uppsala.....	500	0.30	
Varberg.....	297	0.40	“ “
Örebro......	236.2	0.35	“ “
Ornsköldsvik	222.2	0.40	“ “
Ostersund...	720	1.00	Government

KALUNDBORG RADIO[1]

By KAY CHRISTIANSEN

Chief Engineer, Danish Telegraph Administration

Introduction

THE Danish main broadcasting station at Kalundborg was opened in August, 1927. It was projected and built by the Danish Telegraph Administration in close cooperation with the manufacturers of the equipment. The radio transmitter was built by Standard Telephones and Cables, Limited, of London, who have been responsible for several important and successful broadcasting stations. This Company was formerly an Associated Company of the Western Electric Company, Incorporated, of America, who have built over two hundred broadcasting equipments, eighteen of which are of a type similar to the Kalundborg broadcaster.[2] It was these circumstances, together with the comparatively low price, that decided the Administration to adopt this arrangement. So far as relates to the antenna, the construction of the buildings and the placing of the machines, Standard Telephones and Cables, Limited, in all cases approved of the plans of the Danish Telegraph Administration, and on the other hand, the Administration complied with the Company's wishes relating to the station.

Although the transmitter itself was built and tested in London, Standard Telephones and Cables, Limited, conformed to the wishes of the Administration in having the rotating machinery, the transformers, and the switchboards with their instruments and apparatus manufactured by Danish firms. The masts were designed by the consulting engineers, Dr. Nökkentred and Friis Jespersen, and were built by Nakskov Skibsvarft. They constitute a noteworthy example of entirely Danish labour. The construction of the building, and the arrangements therein, were placed in the hands of Kalundborg contractors. The antenna and buried wire earth system were made by the Telegraph Office.

Description of System

Before describing the plant at Kalundborg, it is desirable to give a short description of the entire plant, comprising essential parts at Copenhagen, and the lines interconnecting Kalundborg and Copenhagen, Figure 1.

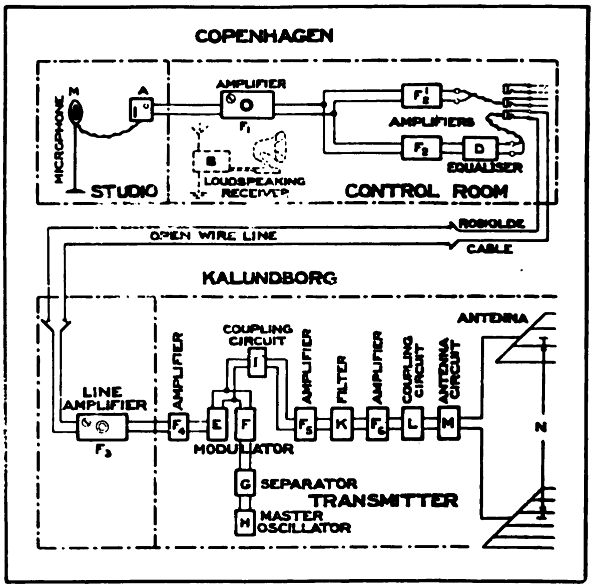

Figure 1—System Diagram, Copenhagen and Kalundborg.

In the studio at Copenhagen is a microphone M, supported on a pedestal that can be moved about so that the microphone may always occupy the proper position with regard to performing artists. The cord from the microphone terminates in a small box, A, in which is mounted a switch for the microphone current and a little lamp which lights so long as the microphone is connected in circuit. From A, the lines are taken to the control-room in which the weak current from the microphone is supplied to F_1, which is a 3-valve amplifier. During the transmissions, an operator is always placed at this amplifier in order to alter the amplification ratio in accordance with the requirements of the music. If, when the amplifier F_1 is adjusted for a "pianissimo" passage to be transmitted at suitable intensity, the music should become "forte," the electric effect would probably be too violent. Hence, the amplification ratio must be reduced. In carrying out these adjustments, the operator is aided by an instrument on which the deviations of a pointer show when the amplification is too high. The operator also has at his disposal a controlling receiver *B*, with which the music transmitted by the broadcast station is received and reproduced by a loudspeaker.

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[1] From an article in "Elektroteeknikeren," Vol. 21, page 497.

[2] Editor's note: These eighteen stations are distinctive by having a separate master drive oscillator. The combination of this feature with low power modulation was first introduced by the International Standard Electric Corporation. Kalundborg was the first station to go into operation with this improvement.

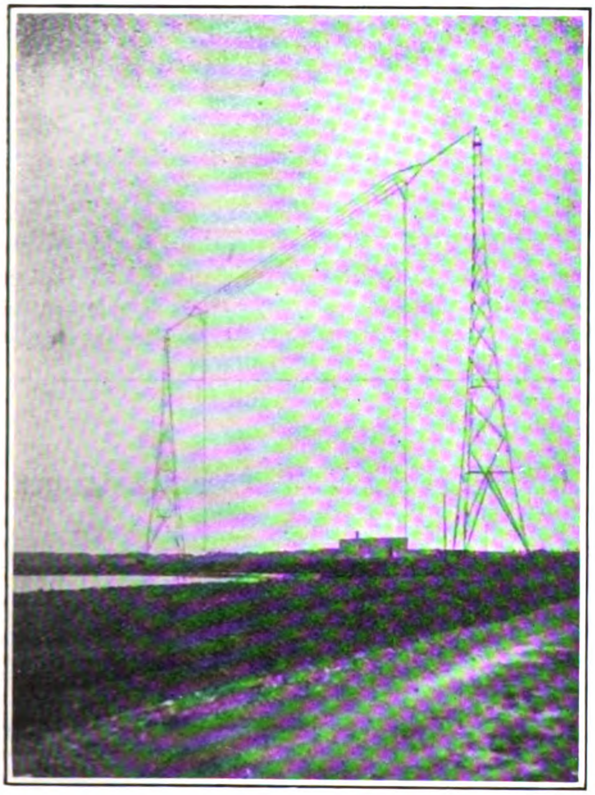

Figure 2—Transmitting Station, Kalundborg.

If only one broadcast station is operating, the current from F_1 goes direct to the line; but often the same microphone arrangement is employed both for the station at Copenhagen, and for the station at Kalundborg. In this case, the current is branched off to two amplifiers, F_2 and $F^1{}_2$. The outputs from these two amplifiers are then connected to the two lines to the stations. Amplifiers F_2 and $F^1{}_2$ are used in order to prevent noise in one line from troubling the other station.

Before reaching the line to Kalundborg the current from F_2 passes through an equalizer *D* which serves for correcting the distortion produced by the line. The connection to the line is by means of cords, so that it is possible quickly to switch over to a reserve line. From Copenhagen to Roskilde, the line consists of particularly heavy type cores in a Krarup cable. From Roskilde to Kalundborg, the line is open wire line. The cable has the disadvantage that it attenuates the high tones more than the low ones. The equalizer *D* corrects for this disadvantage by favouring the high tones.

When the speech current arrives at Kalundborg, it is amplified by means of a special line amplifier (repeater) F_3, after which it is impressed upon the radio transmitter comprising a series of different pieces of apparatus.

The first stage is an amplifier F_4, slightly larger than the amplifiers above mentioned. Its plate voltage is 800 volts. The amplifiers previously mentioned have plate voltages of 150 to 350 volts. The next stage is the modulator, the main components of which are two tubes (*E*) and (*F*). The speech is impressed upon the grid circuit of one of them (*E*), whereas the other (*F*) receives the high frequency oscillations generated by the master oscillator (*H*) and amplified by a "separator" (*G*) before being impressed on the grid of tube (*F*).

It will be explained later that the result of the operations of the modulator is that the speech or music—which is considered to comprise tones of frequencies from 30 to about 10,000 cycles per second—produces intensity variations in the high frequency current, the frequency of which in this case is about 261,000 cycles per second. The intensity variations correspond exactly to the speech or music. The modulated high frequency current now passes coupling circuit (1) functioning as a filter for removing all undesired components from the current. The pure high frequency current—the variations in amplitude of which represent an "image" of the speech transmitted—is passed on through an amplifier (F_5), a second filtering circuit (*K*), amplifier (F_6), and coupling circuit (*L*), which eventually impresses the energy on the antenna circuit (*M*) in which the antenna proper (*N*) is the part transmitting the high frequency oscillations to the ether. The oscillations are still of the frequency determined by the master oscillator; viz., about 261,000 cycles per second, or, in other words, the wave length is about 1,150 metres.

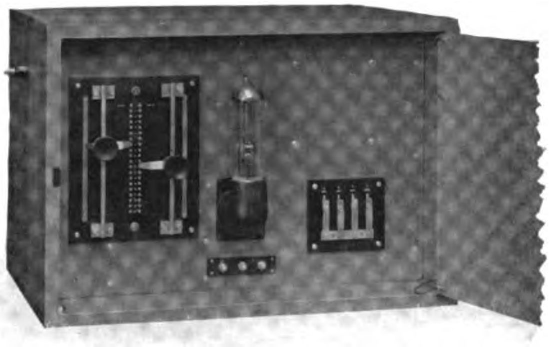

Figure 3A—Master Oscillator.

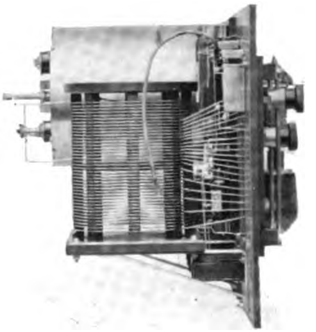

Figure 3B—Master Oscillator (Interior view).

Method of Operation—Transmitting Station, Kalundborg

The transmitting station is built on the peninsular Gisselöre in the neighbourhood of Kalundborg (Figure 2). The station is here as close to the centre of the country as is possible without necessitating the use of sea cables in the transmission circuit between studio and radio transmitter. The place is very suitable for broadcasting purposes, as the surrounding country is flat.

The object of the master oscillator is to provide the high frequency alternating current to be used as a carrier wave, and at the same time to secure constant frequency. The oscillator is a valve oscillator of low energy. It is contained in a metallically screened box (Figures 3*A* and *B*), and it is in principle a Colpitts circuit, characterised by having capacitive reaction.

From the master oscillator, the high frequency energy is taken to the "separator" which is an amplifier tube of the same size as that used in the master oscillator. The object is both to amplify the carrier wave, and to separate the master oscillator from the modulator, so that changes due to the latter do not react on the master oscillator.

From a potentiometer provided with both coarse and fine adjustment, the carrier wave after suitable amplification is taken to the modulator, the circuits of which are shown in Figure 4. The modulation is in accordance with the Heising system, which is often called the "constant current" system. Two identical tubes (*A* and *B*) both receive their plate voltages through a large inductance (*C*). This inductance has the effect of opposing variations of the current at audio frequency; consequently, if the plate currents of the two tubes are I_1 and I_2, the sum of I_1 and I_2 is constant. The speech current is supplied from an amplifier comprising a single 50-watt tube to the grid circuit of tube *A*, which thus means that I_1 varies in accordance with the speech. In other words, as $I_1 + I_2$ must remain constant, I_2 must vary with the speech in such a way that I_2 is large when I_1 is small, and vice versa.

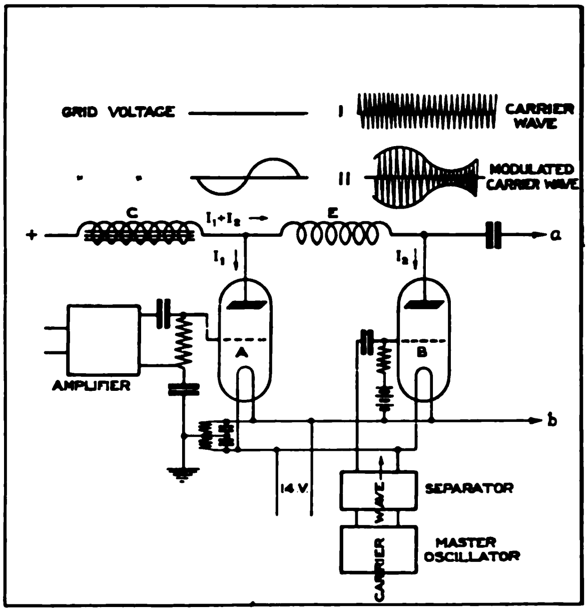

Figure 4—Modulating System Circuit Schematic.

The carrier wave is taken from the separator to tube (*B*) in which the high frequency current is amplified before passing on in the direction of *a-b*, choke coil (*E*) being inserted to prevent the high frequency current from flowing towards the left. The modulator will now operate so that the high frequency current (the carrier wave) flows in the plate circuit of *B*, and its amplitude (indicated by *I*) will remain constant so long as no talking takes place. It has been shown, however, that when speech current is supplied to tube (*A*), I_2 will vary in accordance with the speech; viz., the plate voltage of (*B*) will vary in accordance with the speech. *B*'s operation as an amplifier is, therefore, no longer undisturbed, but *B* will amplify the impressed carrier wave more or less according to whether the plate voltage is high or low. Consequently, the amplitude of the carrier wave will vary in accordance with the speech (see II of Figure 4), that is to say, it is modulated.

The remaining apparatus in the transmitter only serves for filtering and amplifying the modulated carrier wave. In Figure 5 is shown a circuit diagram of the transmitter in which the parts of the apparatus mentioned above are easily recognised; viz., the master oscillator, the separator and the modulator, indicated by *A*, *B* and *C*, respectively. It is here necessary to indicate only the approximate values of the power. The master oscillator, the separator, and the tube amplifying the speech before it is impressed on the modulator, are all of 50 watts, whereas the two tubes of the modulator are 250 watts each.

The modulated carrier wave is now impressed on interstage circuit (*D*). The voltage drop across condenser (*E*) is transferred to the succeeding amplifier which comprises four 250 watt tubes in parallel. (*F*) is a large blocking condenser of high capacity so that, as far as high frequency currents are concerned, the resistance (*G*) may be considered as a shunt to condenser (*E*). (*G*) is provided in order to make the damping in circuit (*D*) so high that the resonance curve becomes broad enough for including both "sidebands"; (*G*) also provides such conditions that variations in the input impedance of amplifier (*H*) do not react upon circuit (*D*). The current is now filtered again in an interstage circuit (*I*) before finally being impressed upon the high power amplifier (*K*). This amplifier comprises two water-cooled tubes each capable of handling approximately 15-KW at 12,000 volts. The two tubes are connected in parallel and receive their plate voltage from the rectifier arrangement (*O*) which obtains its power from a 3-phase, 220-volt, alternating current produced by a motor alternator placed at the station. The plates of the rectifier tubes are water-cooled

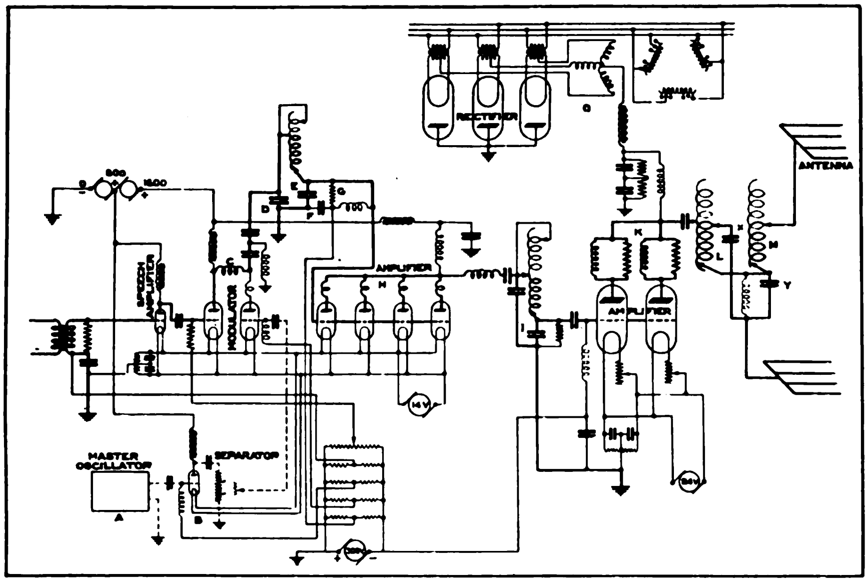

Figure 5—General Circuit Schematic for Radio Transmitter.

and earthed. Consequently, the filaments and the secondaries of the transformers supplying the filament voltage possess a potential in respect to earth. The rectified voltage of about 12,000 volts is passed through smoothing condensers and inductances in the usual manner, in order to be freed from ripple. Before being impressed upon the antenna circuit by way of a capacitive coupling, the entire energy is passed through another filtering circuit.

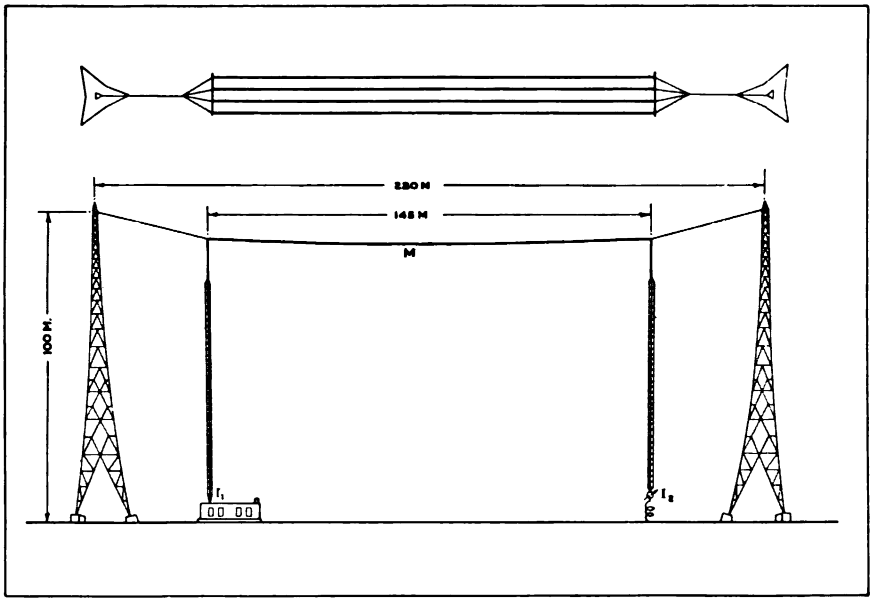

Figure 6—Antenna System.

A motor alternator supplies, in addition to the alternating voltage for the rectifier plant, a voltage for three motor generators for the plate, filament and grid voltages. Of the three generators, one supplies a 16-volt filament voltage and 800- and 1600-volt plate voltage for the air-cooled tubes. Another provides the grid-biasing potentials for all the tubes. The third provides the filament voltage (24 volts) for the two water-cooled tubes.

The antenna is suspended between two masts, 100 metres high, spaced 220 metres apart (Figure 6). The effective antenna length being only 145 metres, there is a considerable distance between the current-carrying leads and the masts, so that the losses therein are highly reduced. The antenna comprises four wires and a downlead at both ends. One of these leads terminates at the transmitter; the other connects through a tuning coil to the earth network, which mainly consists of a great number of copper wires buried in the earth and spaced about a metre apart, at right angles to the direction of the antenna.

When the antenna is correctly tuned, the currents I_1 and I_2 in the two downward leads are equal. At the midpoint, *M*, of the antenna, the current is zero and the voltage a maximum. It is considered that the advantages of thus making the antenna oscillate in two halves are that the current distribution to the earth network becomes more effective and produces smaller earth losses. The two downward leads further provide stable antenna construction.

By modulating the carrier wave, a whole series of frequencies arises among which the carrier wave itself and the "sidebands" are predominant and are those wanted in the case of ordinary broadcasting. This band of frequencies is used, in the case of ordinary detection, in the detector of the receiver for reproducing the speech.

The ideal broadcast station should transmit at constant volume a frequency band comprising the entire radio frequency band from 0 to 10,000 cycles. This has not yet been accomplished. A broadcasting station which is to work well in practice must at least be able to reproduce the range from 100 to 5,000 cycles, and a station employable for speech transmission only must reproduce the range from 200 to 3,000 cycles.

The total widths of the carrier and the two sidebands are in the three cases 20,000, about 10,000, and about 6,000 cycles per second, respectively. The Kalundborg station which uses a carrier frequency of about 261,000 periods should thus, if it were an ideal station, be able to transmit at the same intensity all frequencies from 251,000 to 271,000 cycles (the corresponding wave range is from about 1,110 metres to about 1,195 metres). This means that all the oscillatory circuits—including the antenna circuit—must possess a certain band width.

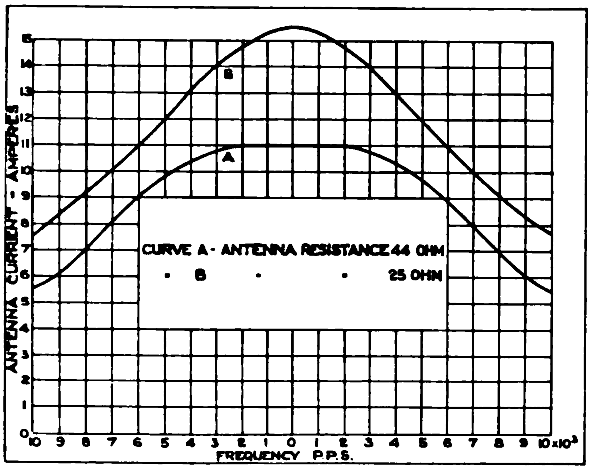

Figure 7—Overall Band-width Curves of Kalundborg Transmitter.

Operating Characteristics—Kalundborg Transmitter

Figure 7, the resonance curve of the Kalundborg transmitter, shows the antenna current as a function of the frequency. Curve *A* corresponds to an antenna resistance of 44 ohms, and curve *B* to an antenna resistance of 25 ohms. The actual curve lies somewhere between the two, the actual antenna resistance being 36 ohms. The resonance curve is consequently broad—and must be broad—and the common assertion that this should be regarded as a fault at a station, is incorrect.

Figure 8 shows a transmission curve for the transmitter, approximately as the conditions actually are, the wave length in this case being 1200 metres and the antenna resistance 44 ohms. From 40 to 6,000 cycles, all frequencies are transmitted at exactly the same intensity.

Although the transmission curves are very good, efforts are always being made to improve the characteristics, in accordance with the principle that each part in itself ought to be as perfect as possible. It is worth noting that much better results have been obtained with regard to amplifiers and radio transmitters, than with regard to receivers; receivers, and particularly loud speakers, have much greater faults. It is also far more important that the conditions should be correct at the transmitter, where the amplification ratio of the energy from the microphone to the antenna amounts to something like 2,000 millions.

Safety Features

In a radio transmitter of this power, employing as it does high tension voltages of 800 volts, 1,600 volts and 12,000 volts, it is obvious that arrangements must be provided to protect the operating staff from coming into contact with any apparatus at a dangerous potential. It is also necessary to protect the apparatus from overload. To protect the operators, the equipment is so arranged that meters at high voltage to earth are mounted behind glass screens. When the transmitter door is closed, therefore, there is no danger of an operator coming into contact with any apparatus at a potential dangerous to life. When the enclosure door is opened, a switch operates, and automatically cuts off all high tension supplies.

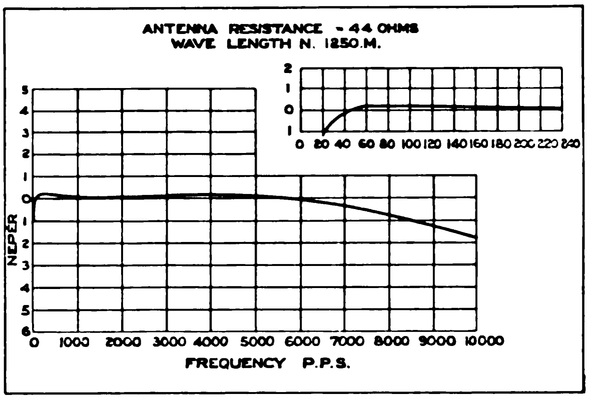

Figure 8—Frequency Characteristic Curve of Kalundborg Transmitter.

In order that an operator may be safe when working within the enclosure, two isolating switches are placed just inside the enclosure. These are opened by the operator as soon as he enters the enclosure. They prevent the application of high tension supply to the transmitter. Thus, if another operator should close the door accidentally and attempt to apply the power, no high tension supply would be obtained, and therefore the person inside the enclosure would be protected.

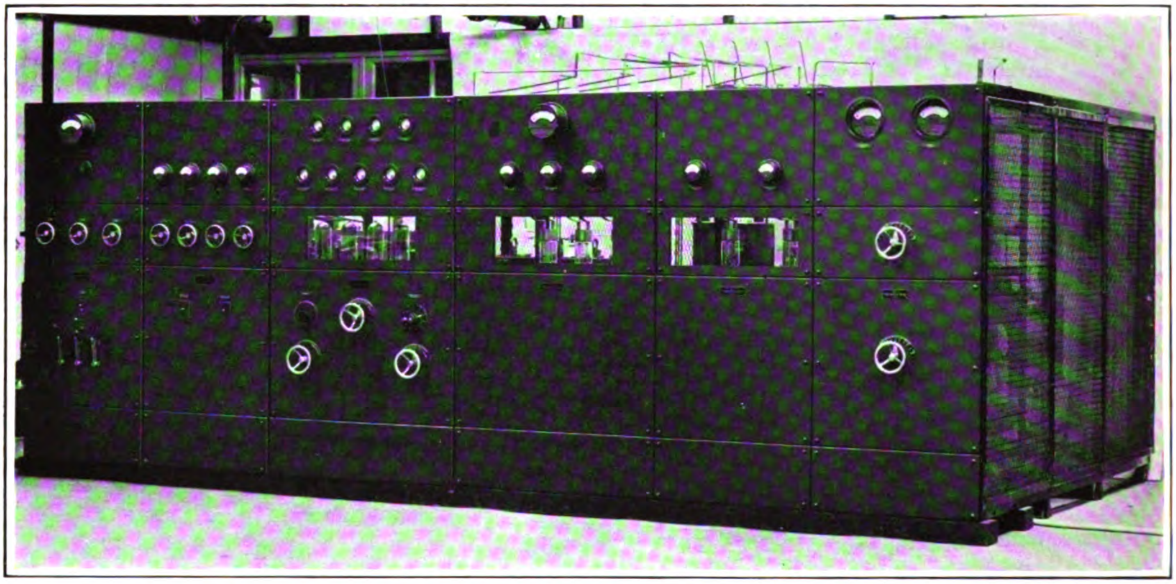

Figure 9—Front View of Radio Transmitter.

To protect the apparatus, the following devices are provided in addition to the normal fuses:

1. Water flow alarm which operates to remove all power to the water-cooled tubes in the event of failure of the water supply.
2. Water temperature alarm, which rings a bell if the temperature becomes excessively high.
3. An overload relay, which protects the 800-volt and 1,600-volt circuits and operates to remove the field from the 800–1,600-volt generator.
4. An overload relay in the 12,000-volt circuit, to protect the water-cooled tubes and to operate to break the supply to the primary of the high tension transformer.
5. Spark gaps, to protect the insulation in the event of high voltage surges: (*a*) Between each phase of the high tension transformer and ground; and (*b*) Across the 12,000-volt smoothing condenser. Resistances are inserted in series with these gaps in order to limit the current when a discharge occurs. In addition to the above, the high tension smoothing choke is protected by a ball gap connected across it.

It may be of interest to note incidentally that an overload relay may be operated, owing to a sudden peak in modulation. In order that the shut-down period due to this cause may be as short as possible, reset buttons are mounted on the front of the radio transmitter. Thus, when an overload relay operates and disconnects the 1,600-volt or 12,000-volt supply, the associated reset button can be operated, whereupon the interrupted supply is immediately re-applied. If the operation of the overload relay was merely due to excessive modulation, the transmitter will continue to operate when the reset button is pressed, but if the overload persists, the overload relay will again operate and remove the supply concerned.

Elimination of Harmonics in the Carrier

It will be noted from Figure 5 that three coupling, or interstage, circuits are employed—between the modulators and the 4-tube amplifier *H*, between *H* and the power amplifier *K*, and between the power amplifier *K* and the antenna circuit. These interstage circuits serve to eliminate harmonics of the carrier frequency as follows:

1. When the closed circuit "*L*" (Figure 5), for instance, is tuned, the impedance of the condenser "*X*" is high at the carrier frequency, but at the frequencies of harmonics, the impedance is very low, and therefore the currents due to harmonics are to a very large extent by-passed to ground.
2. The "driving voltage" of the antenna is proportional to the reactance of the condenser "*Y*." As this reactance is very much lower at harmonic frequencies than at the fundamental, the effect of these harmonic frequencies on the antenna is practically negligible.

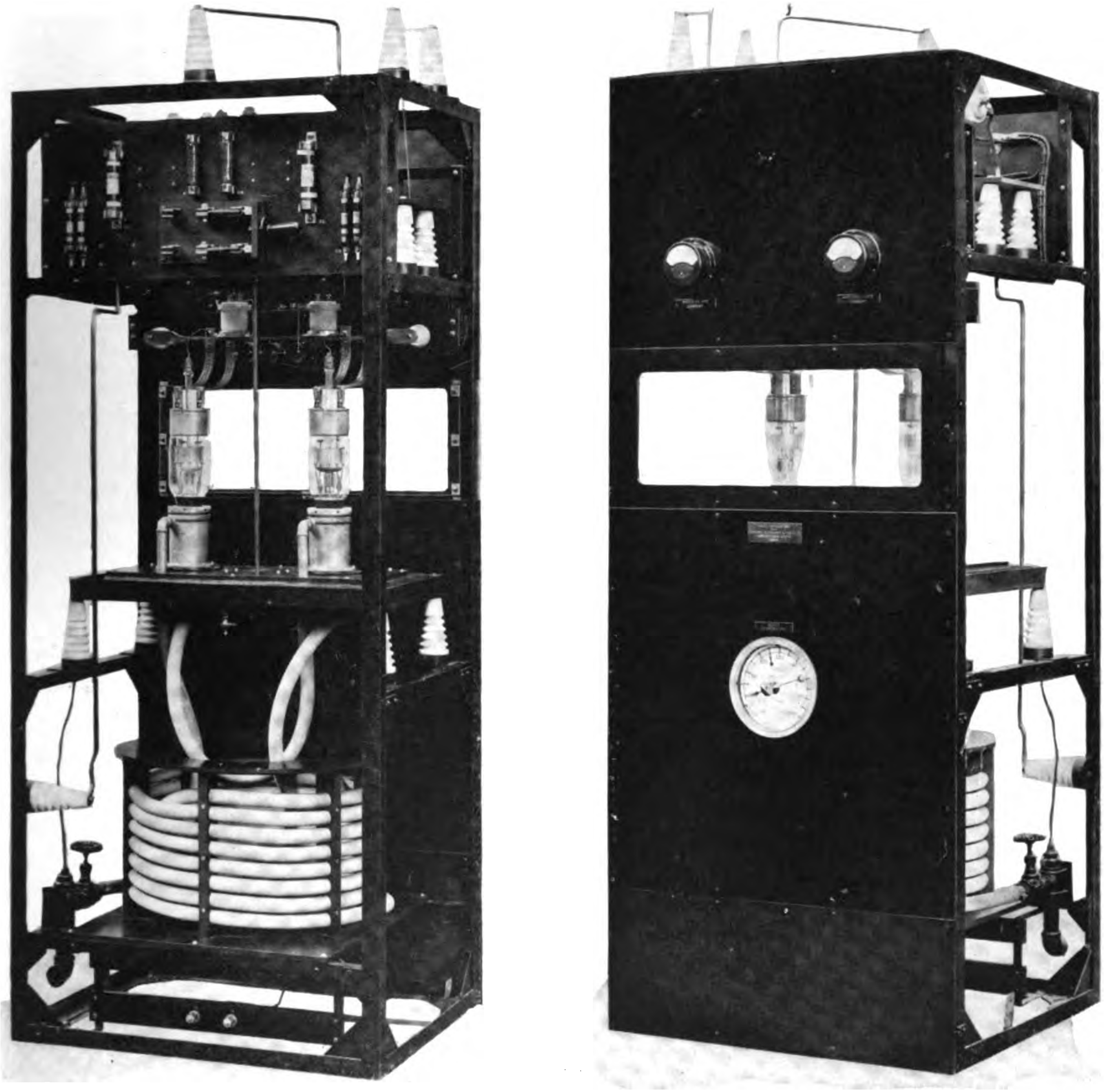

Figure 10—Power Amplifier Unit.

The remarks on the coupling circuit "*L*" also apply to the two interstage circuits "*E*" and "*I*." It will be seen that every effort is made to suppress the radiation of harmonics. The success of these efforts will be appreciated when it is stated that the power radiated due to harmonics is less than one millionth of that radiated at the fundamental frequency.

Transmitter Equipment

Figures 9 to 13 show different views of the interior of the transmitter rooms. Figure 9 is a front view of the transmitter itself. Through the windows the tubes can be seen dimly; first, to the left, the six 250-watt tubes forming the modulator and the intermediate amplifier, then the three rectifier tubes, and finally the two water-cooled tubes forming the high power amplifier.

Figure 10 shows the high power amplifier from both sides. The two water-cooled tubes are inserted into two water-jackets. The water is let in and let out through the long, helically wound tubing, which at the same time serves for providing a suitable resistance to earth. It must be remembered that the potential on the jacket is 12,000 volts.

Figure 11 shows the last panel comprising inductances and a condenser for the circuit before the antenna circuit.

The motor generators for the filament current and the plate voltage were manufactured by A/S Titan and Thomas B. Thrige. Nordisk Elektrisk Apparatfabrik manufactured the switch gear for the motor alternator.

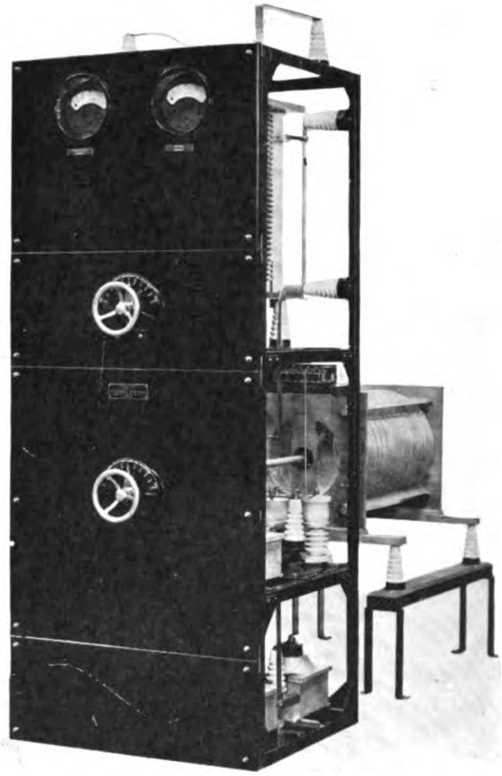

Figure 11—Tuning Unit.

Controlling "Quality" in a Broadcasting System

By E. K. SANDEMAN

European Engineering Department, International Standard Electric Corporation

IN the theory and practice of radio transmission, the term "quality" refers to the degree of faithfulness of reproduction of speech and music afforded by audio frequency apparatus. In view of the importance of quality in contributing to the enjoyment of the listener, and taking into account the large amount of work that has been done in connection with it, the investigation of the quality characteristics of the radio station at Kalundborg, Denmark, is here described to illustrate the nature of the general problem.

The studio of the Kalundborg Station is situated about sixty miles from Copenhagen. Two Krarup loaded pairs in a cable connect the studio to the station, and serve respectively as music line and control line.

On the occasion of the equalisation of the transmission line, at the request of the Danish Telegraph Administration, a number of quality measurements were made on the component parts of the transmission path. These component parts are indicated in Figure 1.

In the absence of extraneous noise and non-linearity, quality is determined by the curve connecting reproduction-efficiency and frequency. If reproduction-efficiency is defined as the ratio of output power to input power, then, in the case of an amplifier, it is greater than unity and, in the case of a transmission line, less than unity. Since, to a practical degree of approximation, equal percentage increases in the energy of the sound produce equal changes in loudness, the loudness L of a sound is proportional to the logarithm of I, the sound intensity, or symbolically, since

$$\Delta L = \text{constant} \times \frac{\Delta I}{I},$$

proceeding to a limit and integrating,

$$L = \text{constant} \times \log I.$$

In computations dealing with quality, therefore, it is customary to plot the logarithm of the reproduction-efficiency rather than the reproduction-efficiency itself. If Napierian logarithms are used, then the reproduction[1] is obtained in Népers (βl) by dividing that logarithm by two. If common logarithms are used, the reproduction is obtained in Decibels (TU) by multiplying by ten, thus,

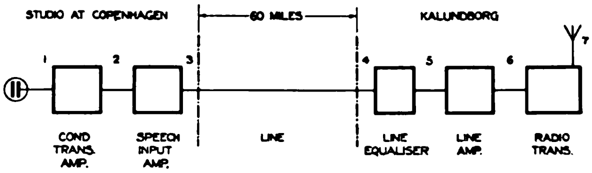

Figure 1—Component Parts of Transmission Path.

$$\text{Népers } (\beta l) = (\tfrac{1}{2}) \log_e \frac{P_2}{P_1},$$

$$\text{Decibels (TU)} = 10 \log_{10} \frac{P_2}{P_1},$$

where P_1 equals the input power and P_2 the output power.

It may be noted incidentally that—

$$\text{Népers } (\beta l) = \frac{1}{2} \times \frac{1}{10} \times \log_e 10 \times \text{Decibels}$$
$$= 0.115 \text{ Decibels.}$$

It is thus evident that whereas attenuation gives rise to a negative number of Népers or Decibels, amplification (gain) gives rise to a positive number of Népers or Decibels. In drawing these curves, it is usual to plot both gain and attenuation as positive quantities; for purposes of combination or comparison, however, an attenuation curve must be inverted before relating it to a gain curve.

Three types of curves are used in this paper in order to indicate the performance of the equipment from a quality standpoint—i.e., gain, attenuation and response curves.

Gain curves are employed in the important case where under normal working conditions the output power is always greater than the input power in a fixed ratio. Gain curves are plotted as ordinates, in Decibels at each frequency, expressing the logarithm of the ratio of output to input power. Each ordinate, therefore, represents, independently of the other ordinates, the gain at the frequency indicated; and the larger the ordinate, the greater the reproduced power for a given input.

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[1] The term "reproduction" is here used to embrace both attenuation and amplication.

Attenuation curves are shown where, under normal working conditions, the output power is always less than the input power in a fixed ratio, which is of importance. Attenuation curves are plotted as ordinates in Decibels at each frequency and express the logarithm of the ratio of input to output power. Each ordinate, therefore, represents, independently of the other ordinates, the attenuation at the frequency indicated and the larger the ordinate, the smaller the reproduced power for a given input.

Response curves are used where the magnitude of any isolated observation of power ratio depends upon the conditions of measurement which may or may not coincide with the working conditions as, for instance, where attenuation through the ether is concerned. Response curves are plotted as ordinates in Decibels above or below an arbitrary zero response, defined as the response at 1,000 cycles, in such a way that positive ordinates indicate more gain (or less attenuation) and negative ordinates, less gain (or more attenuation) than the gain (or attenuation) at 1,000 cycles.

Field Measurements

In making the measurements involved in the Kalundborg Broadcasting Station, each piece of equipment, and the system as a whole, were arranged so that the impedance conditions occurring in practice, were closely simulated. At the input of the system, the equivalent of a generator of constant e.m.f. and of internal impedance equal to that of the apparatus normally connected to the system, was supplied by two series resistances $(\frac{1}{2})R_1$ as illustrated in Figure 2.

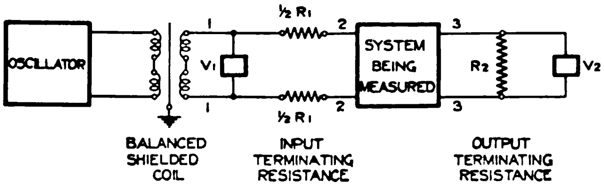

Figure 2—Schematic of General Arrangement for Making Measurements.

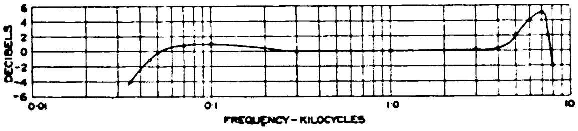

Figure 3—Response from Input of Condenser Transmitter Amplifier to Output of Speech Input Amplifier.

Constant voltage from a valve oscillator was applied at different frequencies to points 1–1. Measurement of this voltage was made by means of a voltmeter at V_1, consisting of a thermocouple in series with a suitable resistance. At the output of the system, a resistance R_2 simulated the terminating apparatus; the voltage across it was measured by means of a high impedance voltmeter which has been coded as the International Standard Electric No. 74,006-N Transmission Measuring Set. The ratio between $(\frac{1}{2})V_1$ and V_2 determined the gain or loss of the system.

In making measurements of this character, it is usual to assume that the terminating impedances are pure resistances. This explains why, in extreme cases—where the impedance values of two pieces of apparatus, joined together under operating conditions, differ widely at certain frequencies from the terminating resistance used in making the measurements—the overall curve obtained by adding the ordinates of the individual reproduction curves, may differ from the observed overall curve. If either piece of apparatus presents towards the other, an impedance which does not vary with frequency, then it is justifiable to assume that the overall characteristic may be obtained by combining the individual characteristics, provided that the measuring impedance for both pieces of apparatus is the same, and is equal to the non-varying impedance. Input and output transformers are frequently so designed that, within the range of reproduced frequencies, the impedance which they present to other apparatus is constant, and approximately of zero angle. The output transformer of the speech input amplifier conforms to this, while the input transformer departs from it slightly. For this reason, it was considered necessary to take an overall characteristic of the speech input equipment only, as shown in Figure 3, while it was not considered necessary to take account of the transition loss between the speech input amplifier and the line.

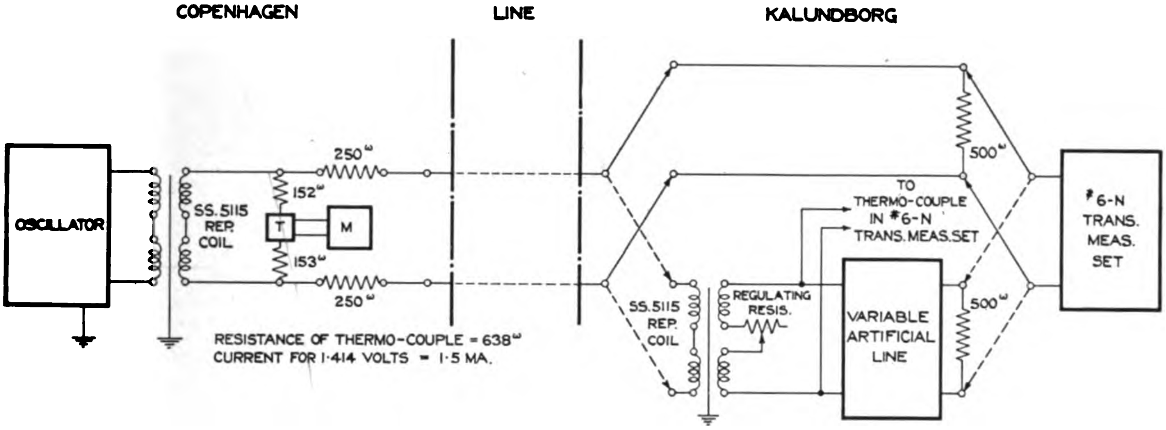

Figure 4—Circuit for Making Attenuation Measurements.

For making attenuation measurements, the arrangements shown in Figure 4 were employed. The alternative circuit obtained by throwing the two double-pole, double-throw switches into the down position was used for calibrating the valve voltmeter in the transmission measuring set. Normally, this set contains means for self-calibration, but these means can be used only when a local oscillator, capable of giving adequate power, is available. The power received over the line was not sufficient for this purpose, hence an additional means of calibration was required.

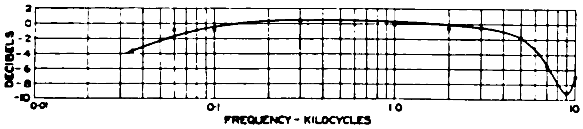

Figure 5—Response Characteristics of Kalundborg Radio Transmitter.

The radio transmitter response measurements (Figure 5) were made with a distortionless receiving set, the circuit of which is shown in Figure 6. The 1,000-ohm resistance, shown in the latter figure in series with the loop, was used for the purpose of broadening the tuning, and so reduced the distortion due to the suppression of the side bands to less than 1/10 Decibel at 10,000 cycles. Two mil wire was used for this resistance, in order to make sure that the deviation of the high frequency resistance from the value measured with direct current would be negligible.

The output circuit was designed as a low pass filter matched into its terminating impedances, and introduces a maximum loss of only 1/8 Decibel at 10,000 cycles, the cutoff frequency being 40,000 cycles.

The circuit arrangement for the response measurement on the radio transmitter is shown in Figure 7, which is practically self-explanatory. The thermocouple is intended to maintain the input approximately constant. The response characteristic is given by the differences between the levels measured at each frequency at points *A* and *B*, and is expressed in Decibels relative to the difference in level measured at 1,000 cycles. Since difference in levels only is required, calibration of the No. 74,006-N set before each reading is unnecessary, and a very considerable saving in the time required for making the measurement may be effected.

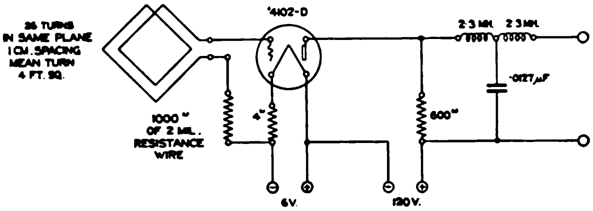
26 TURNS IN SAME PLANE 1 CM. SPACING MEAN TURN 4 FT. SQ.
1000ω OF 2 MIL. RESISTANCE WIRE
4102-D
4ω
2·3 MH.
2·3 MH.
·0127μF
600ω
6V.
120V.

Figure 6—Circuit for Distortionless Receiving Set.

The overall response measurements, from Copenhagen, to the output of the radio transmitter, were made in the same way as the attenuation measurements, the No. 74,006-N set having been connected to the output of the distortionless receiving set, instead of to the line output. The calibrating arrangements, however, were the same as in the case of the line attenuation measurements.

Since gain measurements on amplifiers are every day occurrences, it need only be mentioned that similar conventions were observed in measuring the amplifier in the studio at Copenhagen, as are adopted in making line attenuation measurements and response measurements.

The No. 74,006-N Transmission Measuring Set

As will be evident from the preceding, most of the measurements on the Kalundborg Station involved the use of the No. 74,006-N set. It is designed to measure transmission levels relative to an arbitrary zero level of one milliwatt in 600 ohms. By comparing the levels at two points in a circuit, transmission equivalents of circuits and apparatus and gains of amplifiers may be measured. It is normally intended to operate at any single frequency between 50 and 5,000 cycles per second, but with care, accurate measurements may be carried out in the range of 30–10,000 cycles per second. The set will measure transmission equivalents up to 3 Népers, transmission levels from + 2 to − 3 Népers and gains up to 5 Népers.

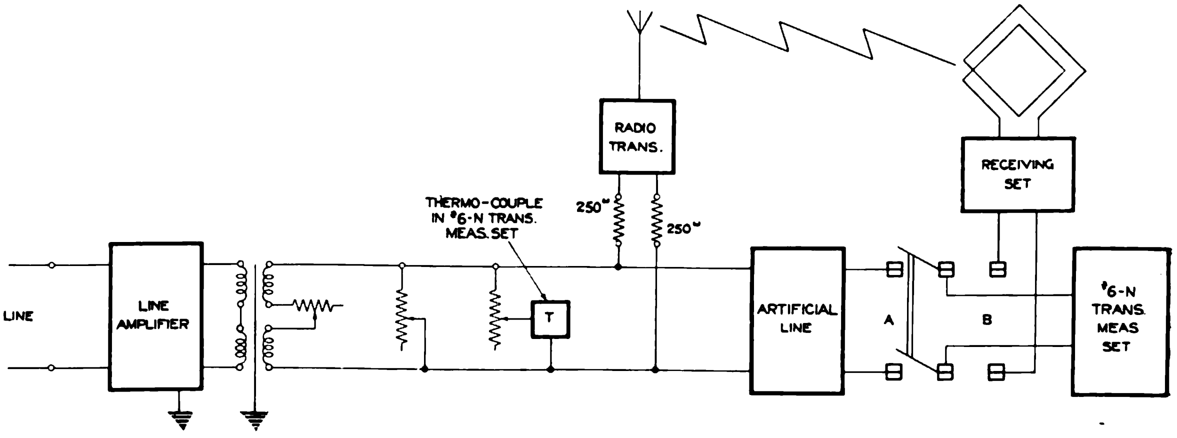

Figure 7—Circuit for Response Measurements on Radio Transmitter.

A photograph of the No. 74,006-G set is reproduced in Figure 8, and a schematic in Figure 9. The only difference between the No. 74,006-G and the No. 74,006-N sets is that the former is calibrated in British Miles of Standard Cable and the latter in Népers.

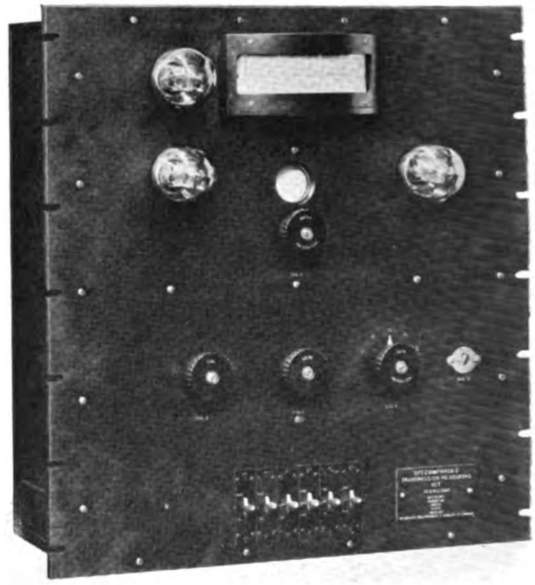

Figure 8—No. 74006-G Transmission Measuring Set.

Attenuation is normally measured by applying to a 600-ohm resistance, in series with the input of the unknown circuit, a voltage such that, provided the unknown circuit has an impedance which is a pure resistance of 600 ohms, one milliwatt will be supplied to it; the level at the output, when terminated with

600 ohms, is then measured. Losses due to departure of the line impedance from 600 ohms are considered to be part of the measured attenuation. If the two ends of the circuit are not at the same place, it is necessary either to employ a second transmission measuring set, or other suitable means to supply the input. (For the present tests, 500 ohms were adopted, instead of 600 ohms, to give agreement with the impedance of the apparatus used.)

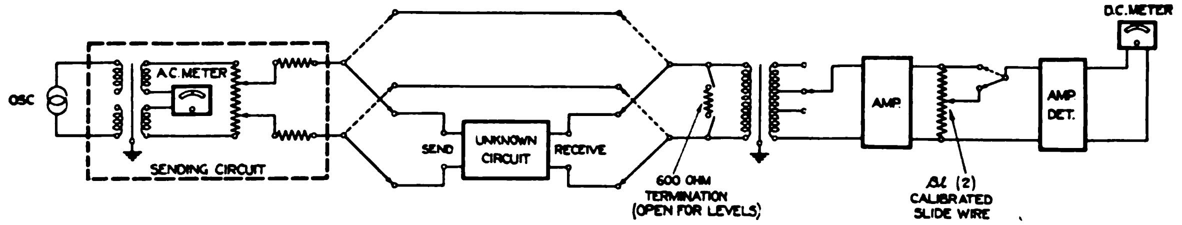

Figure 9—Schematic of No. 74006-G Transmission Measuring Set.

Readings are taken by means of a calibrated slide wire in the valve voltmeter, which is a potentiometer introducing losses, the magnitude of which is indicated in Népers on the dial. By adjusting the sensitivity of the amplifier detector and applying a known level by means of this calibrating circuit, a meter in the anode circuit of the last valve of the voltmeter is arranged to give a standard (usually midpoint) deflection for any given calibrating level with the potentiometer in the most sensitive position. The unknown level is then applied to the input, and the slide wire is adjusted until the standard deflection is obtained. The value of the unknown level is then indicated on the slide wire dial, in Népers, below zero level.

Kalundborg Broadcasting Station—Results of Measurements

The attenuation of the Copenhagen-Kalundborg music line with 500-ohm terminations, before and after equalisation, is shown in Figure 10; that is, points 3–4 and 3–5 of Figure 1. The equaliser shown schematically in Figure 10 is of the shunt type, and was placed at the output end of the line, firstly, in order that the speech-to-noise ratio in the line might be a maximum, and secondly, to avoid impedance complexity at the output of the speech input amplifier across which monitoring apparatus is bridged. While the equaliser was intended only to compensate the line distortion up to 7,000 cycles per second, it is interesting to note the great accuracy with which compensation is realised in practice when the line attenuation curve is smooth. No deleterious effect was observed due to distortion of transients by the resonances in the equaliser.

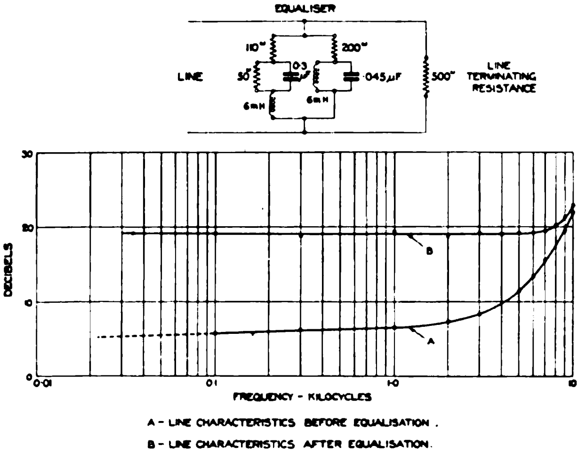

Figure 10—Attenuation of Copenhagen-Kalundborg Music Line Before and After Equalisation.

The attenuation measured from the input (3) of the amplifier at Copenhagen to the output (6) of the line at Kalundborg with 500-ohm terminations is shown in Figure 11.

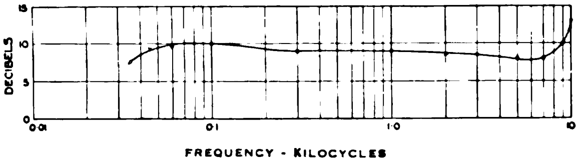

Figure 11—Attenuation of Line + Equaliser + Line Amplifier.

The response of the Kalundborg radio transmitter measured from an input impedance termination of 500 ohms to the distortionless receiving set is indicated in Figure 5. This is equivalent to a measurement from (6) to (7) in Figure 1.

Figure 12 indicates the response from (3), the input to the line at Copenhagen to (7), the output of the radio transmitter at Kalundborg, measured from an input impedance of 500 ohms to the distortionless receiving set.

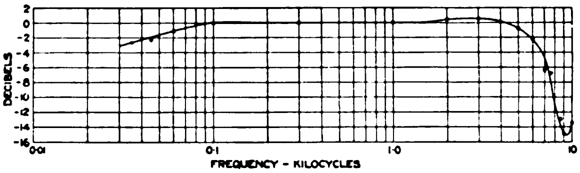

Figure 12—Overall Response from Input to Line at Copenhagen to Output of Radio Transmitter at Kalundborg.

The gain of the speech input amplifier, on full gain operating between 200 and 500 ohms, is shown in Figure 13.

The response curve from (1) the input to the condenser transmitter amplifier to (3) the output of the speech input amplifier is reproduced in Figure 3.

No overall curve—namely, from points 1–7 of Figure 1—was taken, for the reason that the final adjustments of the speech input equipment were made after all measuring gear had been removed from Kalundborg. There is, however, little reason to expect that unusual transition losses at different frequencies would make the result differ materially from that obtained by combining the curves of Figures 3 and 12 by direct addition of ordinates. This addition has been made, and the resulting overall curve from points 1 to 7 is shown in Figure 14.

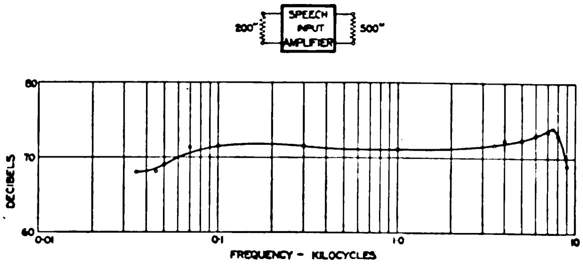

Figure 13—Gain of Speech Input Amplifier.

Within the range of reproduced frequencies, 35–7,000 cycles per second, the curve of Figure 14 represents perfect reproduction, as judged by the ear; and although musical instruments produce frequencies outside of this range, there is not much evidence to show that their æsthetic value is great, even if receiving apparatus were generally available capable of reproducing them, which is not the case.

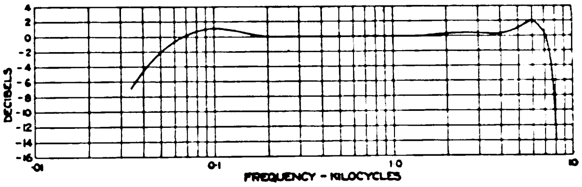

Figure 14—Overall Curve of Whole System.

A response curve is shown in Figure 15, which was obtained from the condenser transmitter of identical type at the laboratories of the International Standard Electric Corporation at Woolwich. Condenser transmitters of this type show only small deviation from instrument to instrument, so that this curve, when combined directly with that of Figure 14 gives the characteristics of the station from air to ether. Since the condenser transmitter was measured in a circuit identical with that in which it was operated, no distortion is introduced by transition loss.

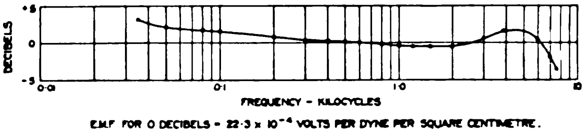

Figure 15—Response Curve of Condenser Transmitter.

Acknowledgment

During the course of the work the author was assisted in a very able manner by Mr. R. O. Carter.

Radio Reception and the Broadcasting System

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Introduction

PROBABLY few persons in any civilised community would to-day fail to recognise a radio receiving set at sight. With its valves, its tuning elements and its whole gleaming array of components, it is to millions commonplace, to hundreds of thousands a fascinating toy, easily put together, easily caused to give results considered eminently satisfactory by the happy maker. Reception from the ends of the earth, ear-piercing volume, speech scarcely understandable—results which would certainly have astounded the radio man of the previous decade—are all that is expected or demanded by many listeners. Unfortunately no more is thought possible by a large section of the public who listen in wonder, and stop listening when their curiosity is satisfied. To them, the ordinary receiving set gives nothing intrinsically satisfying; its musical output is blended with false tones and strange noises, obtained in an intermittent manner after much juggling with numerous dials. Occasionally, however, a set is encountered which has been designed according to definite principles, to meet definite requirements, and the output from which appeals even to the fastidious musical ear. In what follows, these definite principles and requirements are discussed and their application to the design of radio broadcast receiving sets is illustrated.

That highly satisfactory results are possible is due entirely to progress made in the radio industry during the present decade, and more particularly in the application of the three-electrode thermionic valve. It is difficult to find any radio function which in one way or another has not been affected by the advent of this valve. As a detector, it has provided a device of great stability combined with efficiency and comparatively large volume capacity. As a high frequency amplifier it has increased the receiving range; and as a low frequency amplifier it has increased the volume of sound which can be delivered. As an oscillator, it has provided a means of changing the frequency of a tone carrying current. By virtue of reaction or feedback it even gives some control over the resistance of a circuit, and thus over its selectivity. On the laboratory side, it has made available a convenient means of generating steady and undamped high frequency currents; it has simplified enormously all measurements involving high frequencies; and it has made possible the accumulation of trustworthy data by means of which the designer may arrive with comparative ease at the commercial solution of his problems. Nevertheless, the introduction of the valve has not simplified the design of receiving sets. It has brought with it problems of its own—as of stable amplification. It has intensified previously existing problems—the full benefits of amplification, for example, depending on a degree of selectivity far higher than was necessary when amplification was unknown. And in the design of a receiving set of good quality, sensitive, and selective, for broadcast purposes, these problems are found in their full complexity.

The question may be asked, "What are the functions of such a receiving set?" In general terms, they involve:

1. Picking up audio frequency energy carried by radio frequency energy.
2. Translating the radio frequency energy so that the audio signal is made directly available.
3. Delivering the audio frequency energy at a suitable volume level to some reproducing device such as a loud speaker.

The whole process must take place in a manner such that the final output is neither more nor less than an exact replica, in frequency and amplitude variations, of the audio energy actuating the microphone in the particular broadcasting station to which it is desired to listen—and this regardless of whether the station is distant one mile or hundreds of miles, whether it is the only one in the country, or whether it is one of a closely concentrated group.

Such are the functions of the ideal radio broadcast receiving set. How close it is possible to approach this ideal will be seen later.

Before proceeding further, it will be helpful to consider in some detail both the nature of the radio telephone signal as used in broadcasting and the process of translating the "radio" signal to a "telephone" signal. This latter process generally goes by the name of detection or rectification.

Nature of the Radio Telephone Signal

Practically all broadcasting stations at the present time operate on the constant current choke control system, or on some system which gives the same overall result—variation of the amplitude of the radiated wave, combined with constant radio frequency, the amplitude variations following in frequency and relative magnitude the variations of the output from the microphone in the broadcasting studio. Expressed mathematically, and assuming for the sake of simplicity that the output from the microphone is a pure tone,

$$i = A \sin \omega t[1 + k \sin (pt + \theta)], \qquad (1)^1$$

where i = instantaneous value of the modulated current
A = maximum amplitude of the unmodulated current
$\omega = 2\pi f$
f = frequency of the radio current
$p = 2\pi n$
n = frequency of the microphone output current
θ = phase angle of the microphone output current
k = modulation factor, proportional to the amplitude of the microphone output.

It can be shown[2] that k must not exceed unity, as otherwise the envelope of the modulated current will no longer be a true reproduction of the modulating current.

If such an expression be analysed it will be found equivalent to the sum of three undamped components of different frequencies, known respectively as the carrier, upper sideband and lower sideband, and given by the following expressions:

$$\text{Carrier} = A \sin \omega t, \qquad (2)$$

Upper Sideband
$$= -(\tfrac{1}{2})kA \cos [(\omega + p)t + \theta], \qquad (3)$$

Lower Sideband
$$= +(\tfrac{1}{2})kA \cos [(\omega - p)t - \theta]. \qquad (4)$$

The carrier component corresponds, of course, to the unmodulated radio current, while the upper and lower sidebands carry the tone which is being transmitted. The sideband frequencies differ from the frequency of the carrier by plus and minus the modulating frequency, respectively; their amplitudes are equal and proportional to the modulation factor—viz., to the amplitude of the microphone output—and their phases are inverted. In order to secure true reproduction of the transmitted wave, therefore, it is essential that the receiving set should be capable of picking up and passing on with equal efficiency all frequencies between $(f + n)$ and $(f - n)$. Notwithstanding the "constant frequency" of the broadcasting transmitter, the receiving set must handle with uniform efficiency a band of frequencies whose midpoint is that of the carrier, and whose width is $2n$, where n is the highest tone frequency it is intended to transmit. Unless this is accomplished, the input to the translating or detecting device will not be a complete replica of the radiated wave, and the detected output will be modified accordingly. In practice, n is not less than 5000 for good reproduction of music; even this relatively high value is rather low for absolute faithfulness, but only an extremely critical ear will notice the slight loss of quality incurred by this restriction.

Detection

As regards detection, the operation of all the detecting devices in common use depends upon the curvature of the input-output characteristic; viz., on the output containing a term proportional to the square of the input.

Assuming that there is applied to the input terminals of the detector a voltage proportional to the modulated radio current, as given by equation (1), and that the instantaneous output current of the detector is related to the input

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[1] John R. Carson, Proceedings Institute of Radio Engineers, Vol. 7, p. 187, 1919.

[2] R. A. Heising, Proceedings Institute of Radio Engineers, Vol. 9, p. 305, 1921.

voltage by the equation,

$$i_D = a + be + ce^2, \qquad (S)$$

where i_D is the output current and a, b, and c are constants for the detector, it will be found that the output contains a whole series of terms which can be grouped as follows:

(*a*) Amplification terms exactly proportional to the input; viz., frequency and relative amplitude proportional to the carrier and the two sidebands

(*b*) Three steady current terms derived from the three components of the modulated wave. They are

$+ (\frac{1}{2})A^2c$......from the carrier,
$+ (\frac{1}{8})k^2A^2c$....from the upper sideband,
$+ (\frac{1}{8})k^2A^2c$....from the lower sideband.

(*c*) Two terms of the required output audio frequency,

$$+ (\tfrac{1}{2})kA^2c \sin (pt + \theta)$$

derived from the upper sideband component, and

$$+ (\tfrac{1}{2})kA^2c \sin (pt + \theta)$$

derived from the lower sideband component. These two terms, equal in amplitude, frequency, and phase, add together to give $kA^2c \sin (pt + \theta)$ which will in the future be referred to as the true audio output.

(*d*) An audio term of double the modulating frequency, derived from the two sidebands, and equal to

$$- (\tfrac{1}{4})k^2A^2c \cos 2(pt + \theta).$$

This is of the nature of a distortion term, and cannot be eliminated unless one of the two sidebands is eliminated.

(*e*) Double radio frequency terms derived from each of the three components of the modulated wave

$$\begin{aligned} &- (\tfrac{1}{2})A^2c \cos 2\omega t \\ &+ (\tfrac{1}{8})k^2A^2c \cos \{2(\omega + p)t + 2\theta\} \\ &+ (\tfrac{1}{8})k^2A^2c \cos \{2(\omega - p)t - 2\theta\} \end{aligned}$$

(*f*) A term of twice the carrier frequency, and of amplitude proportional to the square of the modulation factor,

$$- (\tfrac{1}{4})k^2A^2c \cos 2\omega t.$$

This term is due to beats between the two sidebands.

(*g*) Terms of twice the carrier frequency, plus and minus the modulating frequency, of amplitude proportional to the modulation factor,

$$- (\tfrac{1}{2})kA^2c \sin (2\omega t + pt + \theta)$$

derived from beats between the carrier and upper sideband components, and

$$+ (\tfrac{1}{2})kA^2c \sin (2\omega t - pt - \theta)$$

derived from beats between the carrier and lower sideband components.

Of these groups, (*c*) and (*d*) are the most important as they fix directly the character of the audio output. Group (*a*) is also of importance, as its presence leads to the possibility of reaction or feed back, intentional or accidental. Group (*b*), which is proportional to the amplitude of both carrier and sidebands but which is independent of carrier and modulation frequencies, has no direct effect either on the character or the intensity of the output; it is, however, one of the most useful groups in connection with signal strength measurements, and in certain cases it is useful in facilitating adjustment of the tuning elements. Groups (*f*) and (*g*) are of no direct use, but their presence must be noted as they may appreciably affect the performance of an amplifier in which detector action due say to overloading of the valves occurs.

It will be noticed that quite a number of these terms are due to the presence of both sidebands. If one sideband were completely eliminated, the character of the audio frequency output would be improved, as the double frequency term in group (*d*) would disappear. In the case of broadcast transmission, such complete suppression of one sideband only, leaving the carrier and the other sideband untouched, is unfortunately not practicable. Assuming that both sidebands are unavoidably present, each contributes to the true audio frequency output, and must be fed to the detector with the same efficiency as the carrier component in order that the set may deliver an audio output truly proportional to the modulating signal.

So far there has been considered only the case of pure tone modulation. In reality the modulating tones are usually complex, and the modulated current may be represented by

$$i = A \sin \omega t [1 + \{k_1 \sin (p_1 t + \theta_1) + k_2 \sin (p_2 t + \theta_2) + \cdots\}].$$

In this expression A and ω have the same meaning as before, while k_1, p_1, θ_1, etc., represent the modulation factor, frequency, and phase of the various components which make up the complex tone. Analysing this equation, we get as before a carrier component, a number of upper sideband components of frequency $f + n_1$, $f + n_2$, etc., with amplitudes proportional to $(1/2)k_1 A$, $(1/2)k_2 A$, etc., and a corresponding number of lower sideband components. Applying such a complex modulated signal to a square law detector, it will be found that the output contains within the audio range a complex tone $A^2 c \sum k \sin (pt + \theta)$ which is the desired term, a distorting complex double frequency tone proportional to $(1/4)A^2 c \sum k^2 \cos 2(pt + \theta)$ and a number of distorting components of frequencies equal to the sums and differences of the modulating tone component frequencies taken in pairs, and of amplitudes proportional to $(1/2)k_1 k_2 A^2$, $(1/2)k_1 k_3 A^2$, etc., corresponding to the pairs of frequencies n_1, and n_2, n_1 and n_3, etc.

The foregoing analysis is applicable to practically all types of detector which it is economically feasible to use in receiving sets for home reception. It holds good, however, over only a limited range of amplitude. Above this limited range saturation effects come into play, shown up generally by the presence of terms corresponding to the third and fourth powers in the curve connecting input and output of the detector. Both of these introduce audio frequency harmonic terms in the output, and in addition the fourth power gives rise to amplitude distortion of the modulation frequency audio output, usually in the form of a decrease in amplitude by amount $d(3/2)k \sin (pt + \theta)A^4(1 + (3/4)k^2)$, where d is the fourth power coefficient in the input-output equation, and pure tone modulation is assumed. By the addition of this fourth power term it is usually possible to cover the effective working range of the input to detectors of the crystal type, and those depending on curvature of the anode characteristic. In the case of grid leak detection, the practical amplitude range may be extended still more; there is, however, a definite change in the method of rectification.

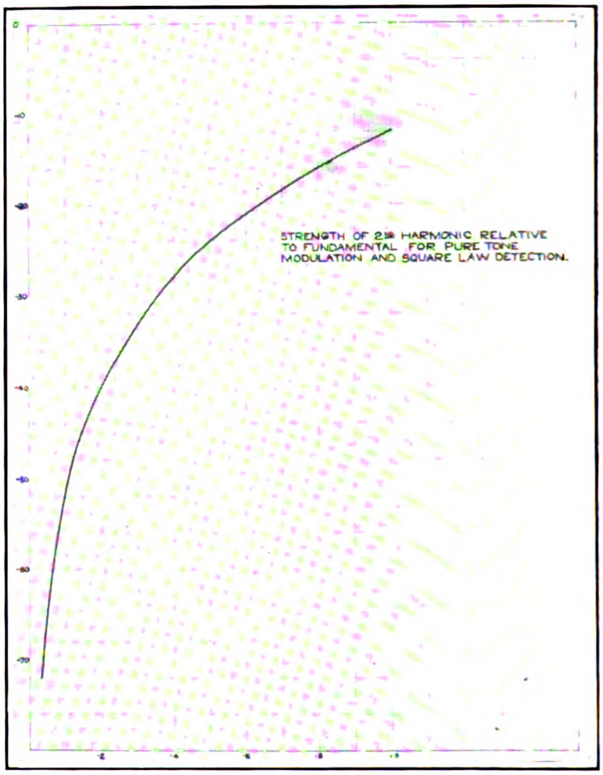


Figure 1—Strength of Second Harmonic.

It may be stated that with all ordinary detectors the safe input range is limited to that over which the square law can be applied, but that this input range can be extended at the expense of a certain amount of amplitude distortion. The amount of the amplitude distortion arising from the presence of an appreciable fourth power term in the input-output equation, and the amount of assymetric distortion due to the introduction of harmonic frequencies arising from the use of both sidebands of a modulated wave and beats between the sidebands in the case of complex tone modulation, are in each case proportional to the degree of modulation. With low modulation it is almost negligible. This is illustrated in Figure 1, which shows the relative intensity of the fundamental and harmonic components for varying degrees of pure tone modulation; in Figure 2, which shows the relative intensity of fundamental, harmonic, and sum and difference frequencies for varying degrees of modulation by a complex tone ($\sin pt + 0.25 \sin 5\,pt$); in Figure 3, which illustrates for a particular case the variation in fundamental output for constant degree of modulation and varying carrier amplitude; and, in Figure 4, which shows for a particular case the amplitude variation of the fundamental due to a fourth power term for constant carrier and varying degree of modulation. Figures 3 and 4 apply to the same detector.

It will be seen from the preceding that the process of detection is not entirely perfect; distortion occurs owing to the introduction of spurious frequencies. Generally speaking, this distortion can be safely neglected. In the first place, all the distorting terms are of the second order of magnitude compared with the fundamental, as they are proportional to the product of the sideband amplitudes, which are usually small relative to the carrier, while the fundamental is proportional to the product of sideband and carrier amplitudes. In the second place, absolutely pure tones are rare; nearly all musical instruments are rich in harmonic tones of sufficient strength to swamp the second harmonics set up in the detector. Thirdly, strong lower tones tend to mask weak higher tones so that they are not perceived. The result of all these factors in combination is that detector distortion arising from beats between the various sidebands is, at its maximum, not perceptible to the average person, and can rarely be detected even by the best musically trained ears.

Before leaving the subject of detection, it is necessary to refer to the grid leak type of detector now in common use. Owing to its performance being a function not only of input amplitude but also of the modulation frequency, this necessitates some modification of the preceding theory. This is obvious when it is remembered that the input impedance contains a capacity element and must, therefore, vary with frequency. On this score the grid leak detector is generally condemned as giving inferior quality to a detector of the anode bend or crystal type whose impedance is—at any rate to a much greater extent—independent of frequency. The objection is, however, academic rather than real; for, provided the input is held within its proper limits and the values of the grid leak and condenser are suitably chosen with regard to the wave length and modulation frequency, it is practically impossible to distinguish between the two types of detectors. "Provided that the input is held within proper limits"—there we have the real weakness of the grid leak detector, in that it has an appreciably smaller "latitude," to use a photographic term, than has the anode bend type. While highly efficient with small inputs (which is the reason for its popularity) it overloads at relatively small volume, this overloading being accompanied by all the amplitude distortion encountered when an anode bend detector is overloaded. With very large inputs, the "grid leak" functioning may entirely disappear, and the valve may actually operate on the curvature of the plate characteristic at the top bend.

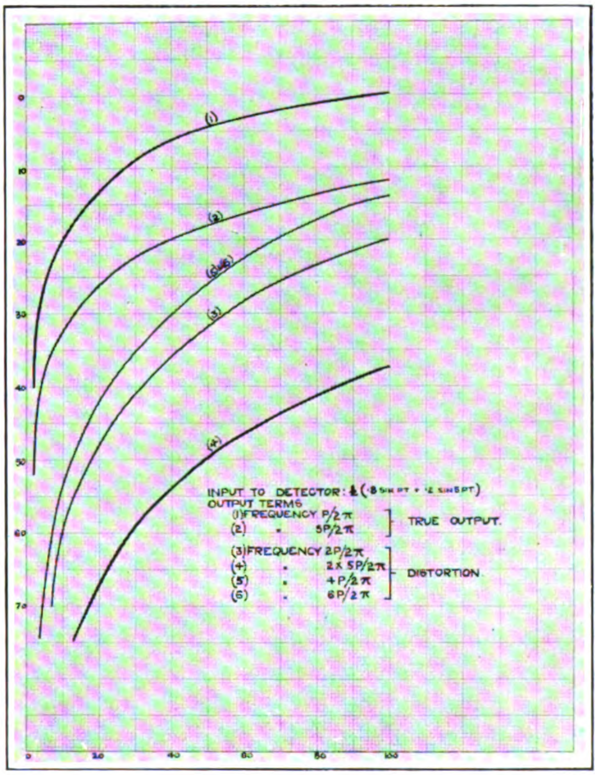


Figure 2—Strength of Harmonics in TU.

The question now arises: How much of the analysis applied to the simple "curvature" detector can also be applied to the grid leak detector? Relative to the latter, no mathematical theory which is not cumbersome to a degree has yet been evolved; it has, however, been fairly well established that so far as the audio components are concerned, the curvature theory can be safely applied over, at any rate, the safe working range, as may be gathered from Figures 3 and 4, both of which apply to a "peanut" valve acting as grid leak detector. As to the terms of double radio frequency, these are considerably reduced owing to the relative short-circuiting effect at that frequency of the reduced grid condenser impedance. From the practical standpoint, therefore, the simple detector theory already outlined may be regarded, so far as considerations of quality are concerned, as including the grid leak type of detector.

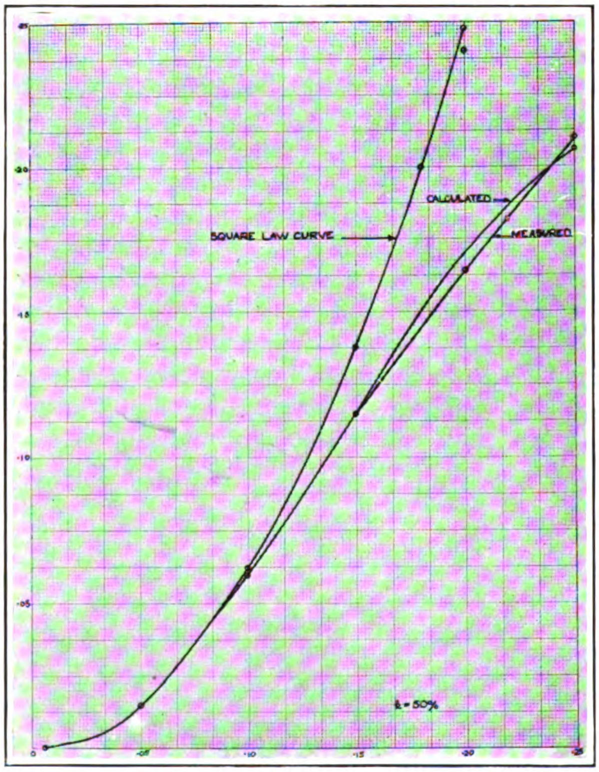


Figure 3—Voltage Output from Detector for Constant Modulation.

So far we have assumed that the received signal has been available at the detector input terminals without reference to the other parts of the receiving system; viz., the collector or aerial, and the selecting or tuning circuits. It is obvious that we require at the detector input terminals the maximum possible signal (within limits) from the desired station, and from the desired station only. The actual magnitude of this input depends upon

(*a*) The field set up by the transmitting system
(*b*) The efficiency of the aerial
(*c*) The efficiency of the tuning system
(*d*) The constants of the detector in use

Electric Field and Aerial Systems

The field set up by the transmitting station is of course entirely independent of the receiving set, the design of which it determines to a large extent. The magnitude of this field is usually expressed in microvolts per metre, the strength of the (vertical) electric field. Its value is a complicated function of the aerial current and aerial structure at the transmitting station, of the wave length used, of the terrain intervening between the transmitting and receiving sites, and also to some extent of the electrical state of the atmosphere, variations in which are generally believed to be the factor governing the phenomenon known as "fading." In daylight the value is fairly steady, and can be roughly estimated by empirical formulæ of the Austin-Cohen type. Figure 5 may be taken as typical of the field strength from a 1 KW broadcasting station at various distances, for transmission over average agricultural land, with no high intervening hills or thick woods in the immediate vicinity of the receiving station. It will be seen from the curve that a "local" station will give, at a distance of three to four miles, a field strength as great as 25,000 microvolts per metre, while a "distant" station, say one hundred miles away, will give a field of only 150 microvolts per metre.

The efficiency of the aerial system depends partly on the type and partly on the details of construction. There are in practice two main types, the "open" aerial usually erected out of doors, and the closed or "frame" aerial of small dimensions for indoor use. Either type may be *aperiodic* or tuned. In general the open aerial is considerably more effective as a collector of energy than is the frame aerial, though not necessarily—indeed not usually—more efficient, taking the efficiency as the ratio of input energy to output energy. The difference in effectiveness is entirely due to the much larger mechanical dimensions of the open aerial.

So far as open aerials are concerned, the designer of a receiving set can only take account of probable electrical constants as determined by the usual amount of space available for the aerial, or the limitation of its dimensions by the law of the land. Figures representative of ordinary practice are—length 100 feet maximum, average about 70 feet; height 20 to 40 feet, capacity 0.0002 to 0.0005 microfarads, inductance approximately 20 microhenries and resistance 20 ohms. Occasionally wide departures from these figures may be encountered due to lack of space, proximity of trees or buildings, the desire to conceal the aerial for the sake of appearance, etc., but for design purposes the figures given above may be taken as meeting the vast majority of cases.

With frame aerials, on the other hand, mechanical dimensions and electrical constants are completely within the designer's control, and their choice is involved in the design of the complete equipment. As already stated, the effectiveness of a frame aerial is less than that of the larger open aerial, but this to a great extent is compensated for by the fact that the frame aerial has strong directional properties, and does not pick up so much atmospheric noise as the non-directional open aerial. Incidentally, it may be explained that atmospheric noise is simply due to the continual readjustment of the electrical state of the atmosphere, and appears as a continuous succession of highly damped electrical disturbances which are scattered over the entire radio frequency spectrum and are not very directional, at any rate over that part of the frequency spectrum occupied by broadcasting. This reduction in noise, due to the directional properties of the frame aerial, contributes materially to the quality of reproduction. In addition to the reduction in general noise, there is the reduction in interference from stations working on the same or very close wave lengths but in a direction forming an angle of say 45 to 135 degrees with the direction of the station being received. This may be considered as giving a degree of selectivity in addition to that obtained by the usual tuning arrangements and in a form which has the special feature that it does not involve the frequency response characteristic and so cannot affect quality by failure to transmit all the sideband frequencies with the same efficiency.

For high grade reproduction, therefore, the frame aerial has distinct advantages over the open aerial, notwithstanding the higher effectiveness of the latter as a collector of signal voltages; and when, in addition to these advantages, its convenience in portability, neatness of appearance and entire absence of disfiguring external wiring and masts is considered, it is evident that the open aerial survives only because it permits the use of simple sets with low running costs due to decreased need for amplification and hence fewer valves.

In designing a frame aerial the main factors to be considered are the "pickup" or signal field collecting power, the minimum wave length to be received, and the resistance. The pickup is proportional to the area-turns, which should therefore be made as large as possible. The area of the frame is, however, subject to limitations on account of general convenience, portability, appearance, etc., and for ordinary domestic use an area of four square feet can seldom

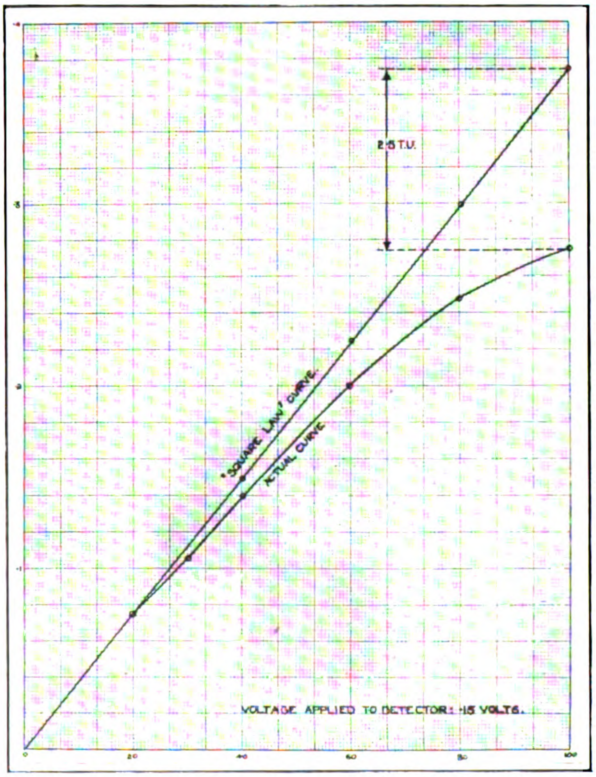


Figure 4—Voltage Output from Detector for Varying Modulation.

be exceeded; this area should approximate to the circular in shape, but for manufacturing reasons a square shape is usually adopted. The number of turns is limited by the minimum wave length it is desired to receive, as governed by the minimum tuning capacity available and the inductance of the frame aerial itself. The minimum tuning capacity is itself a function of the construction of the frame, as it includes the self-capacity of the frame winding, and varies with the spacing of the turns and area of the frame. The resistance of the frame depends upon the type of wire, total length of wire, and distribution of the turns. The problem resolves itself in fact into the design of a tuning inductance for the desired wave lengths and resistance, to occupy a given area as above and to operate in conjunction with a given tuning condenser.

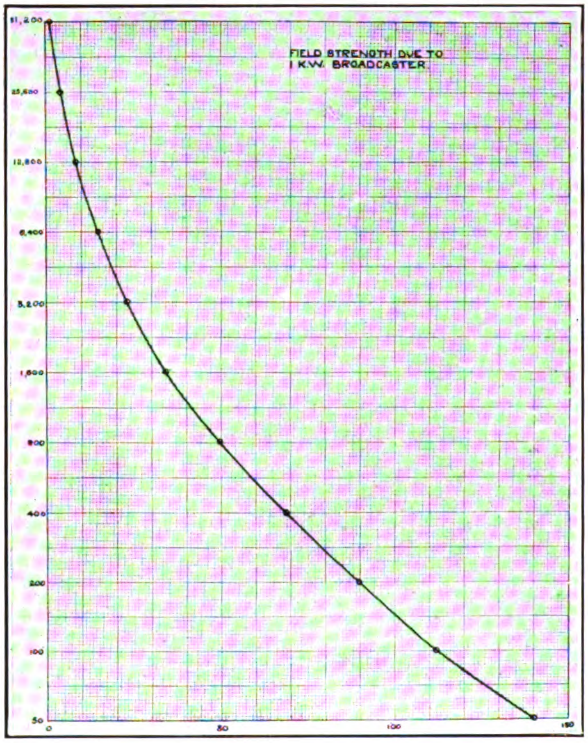


Figure 5.

With the mass of accumulated data now available, the design of a frame aerial is a comparatively simple problem provided the wave length band to be covered is restricted to the normal broadcasting wave lengths of 200 to 600 metres. Most of the aerials in practical use approximate to one of square shape with 2 foot sides and ten to twelve turns with 0.25 inch spacing of stranded wire. Where a larger band of wave lengths is to be covered, as in the case where it is desired to include long wave stations such as Daventry and Radio-Paris, the design becomes a much more difficult problem, as the large number of turns necessary for pickup on the longer waves involve "dead end" and other capacity effects which seriously react on the efficiency when using the aerial for short wave reception. It is absolutely necessary in such cases to sectionalise the frame winding, connecting the sections as required through switches of very low capacity. The standard type of telephone key is quite unsuitable, owing to the high capacity between the springs. In extreme cases it may even be necessary, on account of manufacturing expense, to use fewer turns than the theoretical possible, and compromise by using the maximum practicable number of turns and adding loading coils to bring up the total inductance to the value required for tuning purposes. This is the case, for example, in the No. 44001 Frame Aerial, shown in Figure 12. The single layer winding, carried by four spreaders, has a total of 21 turns of which only 10 are used for pickup and tuning purposes on wave lengths up to 800 metres, the remainder being disconnected and open circuited by means of the switch carried in the box at the foot of the frame. All the turns are used for pickup and tuning on wave lengths between 800 and 1400 metres; while for wave lengths between 1400 and 3000 metres, all the turns are used for pickup purposes and in addition the inductance coils carried in the switch box are cut in by the switch and used in series with the inductance of the frame winding for tuning purposes.

The efficiency of the tuning system must be considered from two aspects. In the first place, tuning—viz., the deliberate introduction of resonance—is necessarily employed in the majority of cases in order to obtain the maximum output from the collector system, which always possesses a certain amount of reactance. Secondly, resonance is employed to enable selection to be made between stations operating on different wave lengths. The inductances and condensers used to balance the reactance of the collector system are, however, not pure reactances, and their presence adds a certain amount to the losses directly associated with the collector; moreover, absolutely sharp tuning or resonance while tending to high selectivity also tends to loss of quality. As already pointed out, a radio telephonic signal is carried not on one frequency, but on a band of frequencies, and a resonant system must inevitably tend to reduce the efficiency of collection or transmission of some of these frequencies at the expense of others. If the resonant frequency of the system is made to correspond to the carrier frequency, then the upper and lower sidebands will be symmetrically attenuated, the attenuation being higher with increase of modulating frequency. In extreme cases this effect is sufficiently serious to render speech very drummy and of low intelligibility, while musical quality is utterly destroyed. Within the normal broadcasting band of wave lengths, the ratio of modulating frequency to carrier is so low that exceedingly sharp resonance is necessary for the effect to be noticeable, and the losses in the components normally used are such that the resonance curve is kept sufficiently blunt to ensure at least a high degree of uniformity in the transmission of all the side frequencies, with correspondingly high quality. If, however, "reaction" or "feed back" is used to bring up the volume efficiency, it does so in effect by reducing the losses in the system, and may easily render the resonance curve of the system so sharp that the failure to transmit to the detector the higher side frequencies is very noticeable in musical items or even in speech.

Bearing these considerations in mind, it will be seen that the efficiency of the tuning system is a rather elastic quantity, depending partly on what is possible in the design of the tuning elements, and partly on what importance is attached to quality as against selecting power. It can be stated, however, that with average apparatus the overall efficiency of the collector (aerial) and tuning system is such that an open aerial will deliver to the detector a carrier voltage of approximately one hundred times the field strength in units per metre while a closed frame aerial will deliver approximately one-tenth that amount, when receiving within the normal band used by broadcasting stations; viz., on wave lengths between 200 and 600 metres. On longer wave lengths the efficiency may be appreciably smaller unless recourse is had to proportionately larger aerials which are not always possible or convenient. There are, however, comparatively few broadcasting stations operating on wave lengths above 600 metres, and such as do exist are of exceptionally high power, which compensates to a considerable extent for the decrease in receiving system efficiency due to limitation of aerial dimensions.

Referring now to the two field strengths already quoted for "average" local and distant broadcasting stations, and using the aerial and tuning system efficiencies as above, we see that

(*a*) The local station will deliver to the detector a carrier voltage of approximately 2.5 volts, receiving on an open aerial, or 0.25 volts, receiving on a frame aerial.

(*b*) The distant station will deliver to the detector a carrier voltage of approximately .015 volts, receiving on an open aerial, or 0.0015 volts, receiving on a frame aerial.

Since practically all detectors available for use in ordinary receiving sets require a carrier voltage of approximately 0.2 volts in order to give a telephone signal of reasonable intensity in head receivers, the local station will give really strong reception; the distant station will, however, probably be quite inaudible, the detector requiring at least thirteen times the available voltage. This increase in voltage may be obtained by interposing some form of high frequency amplification prior to detection. If frame aerial reception is used, the local station will still be able to operate the detector, but the volume will be considerably less than with the open aerial. Assuming that the detector follows the square law up to an input of 2.5 volts, the reduction in signal strength due to substituting a frame for an open aerial will be approximately 40 TU. Few detectors, however, obey the square law over such a comparatively wide range, and the difference in volume between the open aerial and the frame aerial actually will be considerably less than 40 TU, the signal on open aerial being weaker than the theoretical value due to the strong fourth power term—which incidentally may cause appreciable amplitude distortion at such a high input.

Selectivity and Amplification

At this point, it is desirable to consider the set with respect to its selectivity characteristics. Local and distant broadcasting stations, it has been noted, may give signal fields of 25,000 and 150 microvolts, respectively, and the frequency separation between the two stations may be as low as 20,000 cycles. Selectivity, as previously indicated, is attained through the application of the principle of resonance. The question now is, what degree of selectivity is required, and in what way can resonance be applied, so that the receiving set can discriminate between two voltages having a ratio of 25,000 to 150, viz., a ratio of 167, and a frequency separation of 20,000 cycles say in 750,000, corresponding to wave lengths of 400 metres and 411 metres for the two stations. It is apparent that the stronger signal must be attenuated 167 times to give a signal equivalent to that of the weaker, and at least another ten times in order that the distant station may be clearly heard above it, thus giving a requirement of a total attenuation of 1670 of one signal frequency when the set is adjusted for the other signal frequency. Furthermore, provision must be made for obtaining this attenuation at any wave length within the broadcast band.

Given this selectivity, there still remains the question of detecting the weaker signal. As already stated, this must be amplified at least thirteen times, in order to get reasonable audibility and in actual practice an amplification of thirty to forty is advisable, for open aerial reception. If frame aerial reception is desired, the requisite amplification is of the order of three or four hundred.

In addition to the selectivity and amplification required, one other point requires consideration. Some means, obviously, must be provided for controlling the amount of amplification, in order to avoid distortion when receiving a strong signal as from the local station. Such a signal, applied to the detector, through an amplifier capable of raising the distant station signal to a suitable level, would only result in saturation of both amplifier and detector, with accompanying distortion, which probably would be increased as a result of overloading on the output side of the detector.

Grouping these various requirements, it is clearly advantageous to split up the selecting arrangements into two main divisions, the first connected with the aerial tuning system proper, and the other included in the amplifier, so that in proportion as the signal sought for is weak, the necessary amplification is accompanied automatically by increased selectivity. Such an arrangement is almost universal, and tends to simplify the difficulties otherwise involved in constructing high frequency amplifiers which will cover the whole broadcast band without adjustment. This is especially the case in Europe, where it is necessary to arrange sets so that the few, but important, long wave stations such as Daventry and Radio-Paris can be tuned in as well as the stations on the more normal wave length band of 200 to 600 metres in use both in Europe and America. In what follows, therefore, no mention will be made of other than "tuned" systems of high frequency amplification.

The three leading methods of amplifying a radio telephonic signal at the present time are by means of

(*a*) "Reaction"
(*b*) "Tuned anode" valve amplifiers
(*c*) The "supersonic" method

Of these three, only the latter two methods are strictly within the definition, in that the output is truly proportional to the input; but the use of reaction is in practice so closely allied to the use of amplification proper that it seems expedient to deal with it at the same time.

Amplification by reaction is obtained by feeding the signal energy to a valve which is adjusted so as to be just on the threshold of oscillation at the same frequency as the incoming carrier. Under these conditions the incoming signal has a trigger effect and sets the valve circuit into actual oscillation so long as the signal lasts, and power is fed back to the input side, just to balance the power which would normally be expended in that input circuit by the incoming signal. The system as a whole behaves to the signal voltage as though the resistance of the circuits had vanished. Therefore, the signal is able to set up very much larger currents than would otherwise be the case, and the output may be considered as amplified relative to what it would be if no reaction were used. A typical circuit is shown in Figure 6.

Probably no weapon in the armoury of the radio engineer has been more seriously abused than has reaction. It costs little to apply it to any valve detector set; the increase in signal strength is very marked; and the increase in sensitivity is at times enormous owing to the fact that the amplification possible is not a constant but increases almost linearly with decrease in strength of the incoming signal when the latter is weak. It, however, has two very serious disadvantages when applied to a broadcast receiving set. The first disadvantage is that owing to its apparent neutralisation of the resistance of the circuit, very sharp resonance is produced, with attendant loss of quality due to cut off of the higher modulating frequencies, this loss of quality being proportional to the amplification obtained with any particular adjustment of the degree of reaction or feed-back. As a result of the very sharp resonance, selectivity is concentrated in one circuit and its tuning rendered very delicate. The second, and most serious disadvantage, is that unless the greatest care is taken in handling the set, the valve will actually burst into oscillation and act as a low power transmitter which may combine with the broadcast signal to produce an interfering tone which will be picked up by all receiving sets within a radius of a mile or more and thus spoil the reception from the broadcasting station. Moreover, this interfering tone is heard in the originating receiver with considerably greater strength than is the modulated telephonic signal, and there is thus a strong temptation to the user deliberately to bring his set into oscillation in order to facilitate "searching" for a weak station.

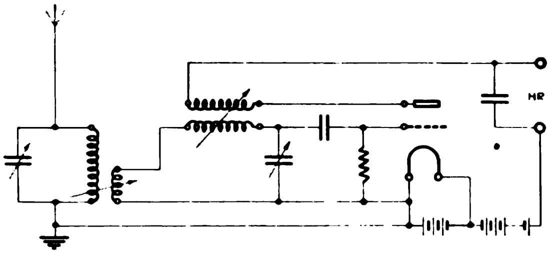


Figure 6—Simple Reaction Amplifying Circuit.

The nuisance arising from the accidental or deliberate misuse of reaction in this way is too well known to need further comment. It must be emphasised, however, that the nuisance arises from the misuse of reaction. If precautions are taken either in actual operation, or by arranging the circuits so that if the set does burst into oscillation little or no energy is transferred back to the aerial, reaction must be regarded as a legitimate tool even in a telephonic receiving set, provided of course that due weight is given to the probable effect on quality. Taking the latter aspect as the governing one, it has been found in practice that an equivalent amplification of ten can be usefully obtained by the application of the feed-back principle. Variations in valve characteristics, however, are such that in order to be sure of reaching this figure it is usually necessary to arrange the circuits so that full control is obtained of the amount of reaction, viz., some adjustment must be provided capable of bringing the set into oscillation; thus, the quality obtained from the set is to a considerable extent dependent on the discretion of the user.

Amplification by means of a tuned anode system is now very common. An elementary circuit is that shown in Figure 7, which illustrates a single stage of amplification feeding a valve detector. It will be noticed that part of the tuning is directly associated with the aerial, additional selectivity being obtained through the resonance of the anode circuit, C.L., only the signals selected being amplified and any others being by-passed. At first sight it would appear that the selectivity of the amplifier portion is dependent only on the constants of the C.L. circuit, that is to say, on the inductive and capacitative reactances of the tuning elements,

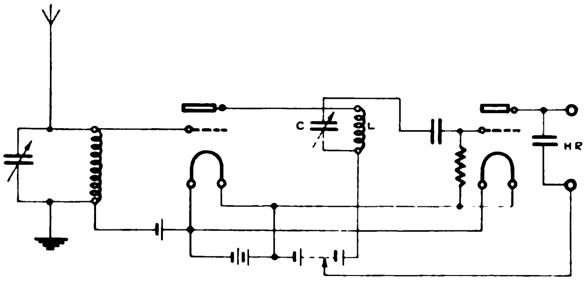


Figure 7—Simple Tuned Anode Amplifying Circuit.

and the resistance of the closed resonant system, due chiefly to the coil itself. This, however, is not the case. The impedance of the amplifying valve must be considered as in series with the e.m.f. feeding the closed system, and as exerting an appreciable damping effect. As a result, receiving sets employing tuned anode amplification as a rule require at least two stages of such amplification if a high degree of selectivity is to be obtained, and with three fairly critical tuning adjustments their use becomes rather difficult unless each adjustment is provided with calibration. Against this disadvantage must be balanced the good quality obtained due to selection in a series of relatively flat resonance circuits avoiding cutoff of the side frequencies. This type of amplifier is increasingly popular for high grade sets in America, where the wave length band is limited; in Europe its good quality is beginning to be appreciated, but the necessity for providing for the long wave stations in conjunction with interchangeable tuning coils has so far deterred manufacturers from taking it up to any great extent.

While the circuit in Figure 7 shows the tuned anode system in its simplest form, and one very common in actual practice, other forms of it are frequently encountered. The resonant circuit, C.L., may be replaced by an air-core transformer with either or both primary and secondary tuned by variable condensers, or the anode may be coupled to the tuned circuit through only a portion of the inductance. All these variations reduce, when analysed, to the equivalent of the simple circuit in the diagram; their chief advantage is that they offer a means of equating the plate load to the impedance of the valve itself, and also offer possibilities of increasing the selectivity at the expense of signal strength. In addition to these variations, where two or more stages of amplification are employed it is generally necessary to provide some form of reversed feed-back to neutralise the feed-back which inevitably occurs through the capacity between the electrodes of the valves, and which might cause serious internal oscillation, or at any rate a tendency to oscillation which would have a disastrous effect on the quality of reproduction. Where only one stage of amplification is employed, the increase in signal strength obtained is seldom sufficient for ordinary work, and it is usual to increase the gain by the introduction of reaction, the circuit being arranged to feed back energy not to the aerial circuit, but to the tuned anode circuit. The interposition of the amplifying valve between the seat of the reinforced oscillations and the aerial is supposed to prevent any re-radiation in the event of reaction being deliberately or accidently pushed so far as to cause the generation of oscillations. It must be acknowledged, however, that this supposition is not usually borne out in practice, for even if no coupling exists between the elements of the various tuned circuits, sufficient energy may be fed back through the valve inter-electrode capacity to cause some disturbance; while it not infrequently happens that before the anode circuit itself is brought to the point of oscillation sufficient feed-back occurs through the valve capacity to set the aerial itself into vigorous oscillation, to the detriment of all other receivers in the immediate neighbourhood. This possibility, however, can be largely obviated if the precaution is taken to provide a compensating reversed feed-back circuit (Figure 8) as employed in the No. 44081 Receiving Set. This set includes one stage of tuned anode amplification with reaction on the tuned anode, and the provision of a neutralising circuit consisting of the balancing condenser B.O. and the inductance coil L. The balancing condenser is equal in capacity to the condenser formed by the grid and plate electrodes of the amplifying valve, while the neutralising coil is coupled to the aerial tuning coil in such a way that the mutual

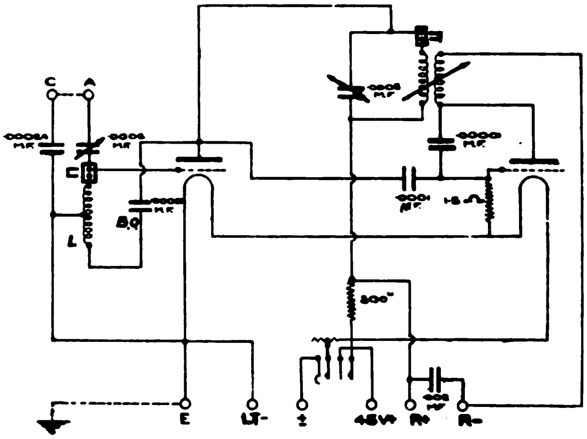


Figure 8—Circuit Diagram of Weconomy Two-valve Detector and Tuner Set.

inductance between the two coils is equal to the mutual inductance between the aerial tuning coil and the complete aerial circuit—viz., to the inductance of the tuning coil itself—but opposite in sign. The operation of this circuit is as follows:

The signal field sets up an e.m.f. in the aerial circuit, and causes currents to flow therein, the corresponding potential across the tuning inductance being transferred to the grid of the amplifying valve; the amplified potential appears across the tuned anode circuit, or effectively between the anode and filament or earth, and in addition to the currents set up in the tuned anode circuit a current is fed back through the valve capacity to the grid and through the tuning coil to earth, inducing in the aerial circuit an e.m.f. corresponding to the magnitude of the current and the mutual inductance between the tuning coil and the aerial circuit as a whole. Another current is driven through the balancing condenser and the neutralising coil to earth, and induces in the aerial circuit an e.m.f., corresponding to the value of the current and the mutual inductance between the neutralising coil and the aerial circuit. Since the magnitudes of the currents are almost entirely dependent on the capacities in their paths, and these capacities are made equal, the currents are equal, while the e.m.f.'s induced in the aerial circuit will be equal but of opposite sign, owing to the sense in which the windings are connected. Thus no voltage set up in the anode circuit of the amplifier will give any effective feed-back, and there is no possibility of re-radiation. For this to be strictly true with the circuit shown, some means should be provided for adjusting the self and mutual inductance of the neutralising coil in accordance with changes in wave length, to correspond with changes of the effective coupling between the tuning coil and the aerial, and changes in phase relationships. In practice, however, it has been found sufficient to fix the adjustments of the balancing circuits once for all, so far as operation over the wave lengths covered by a fixed tuning coil and variable condenser is concerned.

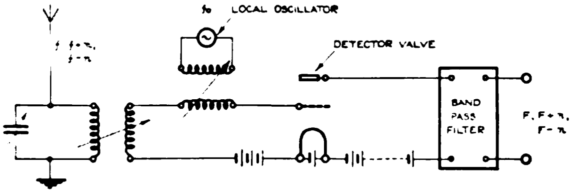


Figure 9—Simple Supersonic Circuit Schematic.

Amplification by the supersonic method presents what admittedly is one of the most remarkable applications of radio technique on the reception side. Practically every possible use of the valve is exploited in turn, from the generation of oscillations to the amplification and detection of oscillations, and the resultant circuit, complex both in construction and in functioning, is yet exceedingly simple in operation, and can be made to yield a degree of selectivity as high as is consistent with good quality of reproduction.

The supersonic system is characterised by two main features: transfer of the signal modulation from the received carrier frequency to another much lower but still supersonic frequency (generally referred to as "intermediate" rather than "supersonic") and amplification of the new modulated carrier in an amplifier designed to deal with that particular carrier frequency only, followed by detection as in ordinary sets. No signal can be amplified unless its frequency is first converted to that intermediate frequency for which the amplifier is designed. The amplifier itself, having to handle only one carrier frequency (of course with the attendant sidebands due to modulation) can be designed for much greater efficiency than is possible in an amplifier covering the whole wave length band used by the various broadcasting stations; while the constants of the selecting circuits in the amplifier can be fixed once for all, and adjusted to pass the frequency band requisite for good quality, with very large attenuation for all frequencies outside this band.

The manner in which the signal modulation is transferred from the original carrier to a new carrier of intermediate or supersonic frequency is indicated in Figure 9. The signal may be received by means of any convenient system, such as an open aerial, and is fed to a detector valve together with a strong voltage from some local oscillator, of frequency $f_0 = f - F$, where F is the carrier frequency for which the amplifier is designed. The total input to the detector is then proportional to

$$A \sin \omega t - (\tfrac{1}{2})kA \cos[(\omega + p)t + \theta] \\ + (\tfrac{1}{2})kA \cos[(\omega - p)t - \theta] + B \cos 2\pi f_0 t,$$

where the first three terms represent the input components due to the signal carrier and the signal sidebands, and B cos $2\pi f_0 t$ is the input due to the local oscillator. Beats will occur between the signal components and the local oscillator component, owing to the ordinary detector action as outlined previously; and amongst a large number of other terms the output of the detector will be found on analysis to contain the following three components:

$$AB \sin 2\pi Ft; \; -(\tfrac{1}{2})kAB \cos[(2\pi F + p)t + \theta]; \\ +(\tfrac{1}{2})kAB \cos[(2\pi F - p)t - \theta].$$

It is obvious that these three components correspond to a modulated wave of frequency F, that for which the amplifier is designed, the modulation being exactly proportional to the original signal wave, $k \sin(pt + \theta)$.

The question may be asked, how is it possible to use a detector at the very beginning of the system, seeing that the whole necessity for using high frequency amplification arises owing to the signal being too weak to operate a detector. The answer is that detection in the initial stages of a supersonic receiving set is not applied to the incoming signal by itself, but to the incoming signal considered as very weak sidebands of the strong local carrier of amplitude which is by design made sufficiently powerful to ensure efficient detection. The amplitude of the resultant intermediate frequency carrier is proportional to the product of the amplitudes of the incoming signal carrier and the local beating carrier, and could be made indefinitely large if the square law of detection held good for all inputs independent of magnitude. As already mentioned, however, the square law of detection holds good for only a limited range of detector input, and a negative fourth power term comes into consideration, the effect of which is to determine a definite optimum value for B. In practice it is advisable to work rather below this optimum value, so as to ensure that the modulation carried by the intermediate frequency wave is an exact duplicate of that carried by the incoming signal wave.

In addition to the required output, the detector delivers terms corresponding to twice the local carrier frequency, twice the frequency of the signal components, etc. These extra components are filtered out either before or during amplification, so that only the modulated wave of frequency F is fed to the final detector. All of these "stray" components are of very much higher frequency than F and there is no difficulty in eliminating them, a relatively simple filter sufficing.

The preceding explanation of the conditions necessary for the transference of the modulation to the intermediate frequency is based on the assumption that the frequency of the local oscillator is lower than the signal carrier frequency by the amount F. It is, however, equally possible to obtain the required transference by using a local oscillator frequency which is higher than the signal carrier by the intermediate frequency. The essential condition is that the difference between the received and local carrier frequencies is made equal to that for which the amplifier is designed. For any particular received frequency there are, therefore, two possible settings of the local carrier

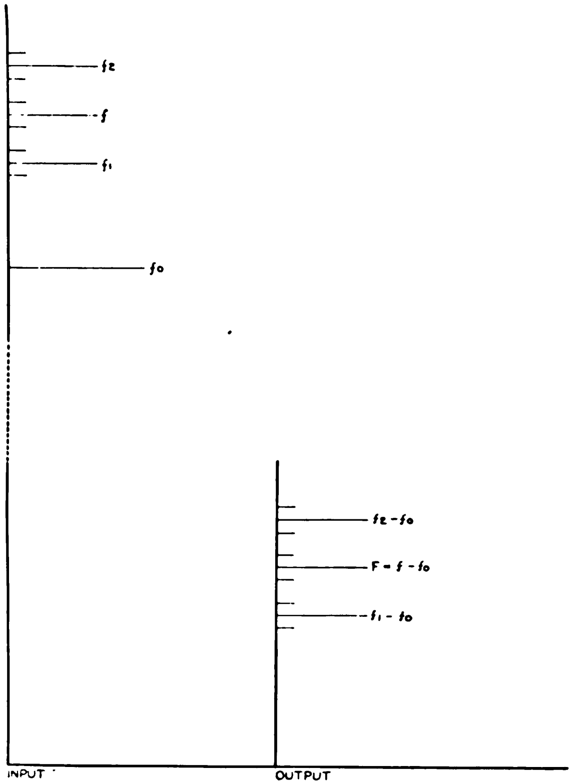


Figure 10 A Figure 10 B

Supersonic Frequency Spectra.

which may be used. That this choice is available is sometimes a feature of considerable value, especially when very severe interference is encountered.

In order to emphasize the fact that supersonic amplification, notwithstanding its complexity, does not involve the employment of methods which in themseves result in loss of quality, the expression "transfer of modulation" has here been used. It is, however, equally correct to view the process as one of changing the carrier frequency from that actually received to that fed to the amplifier. If a number of stations are being picked up simultaneously on various wave lengths and fed to the frequency-changing detector together with some local carrier as above, the received signals will be reproduced on the output side of the detector with all their carriers changed to new values equal to the difference between the local carrier frequency and the original carrier frequencies. This is shown diagrammatically in Figure 10. Here f_0 is the frequency of the local carrier, while f, f_1, f_2, are received signal carriers, each with its own set of sidebands. Figure 10*a* shows their distribution along the frequency spectrum as they are fed to the detector; while Figure 10*b* shows the distribution of the output along the frequency spectrum. Everything is displaced, but the numerical separation between the various elements is unaltered. The result is that the percentage difference between say the carriers f and f_1 is much greater after the frequency changing than originally, and hence it is very much easier to separate one from the other by means of resonance or band pass filters. This feature accounts to a great extent for the extraordinary selectivity which it is possible to attain with supersonic receiving sets. In fact, the selectivity obtainable on the output side of the detector is so great that care must be taken not to allow it to become excessive, otherwise some of the upper side frequencies of the desired signal will be cut off. Tuned anode circuits are especially dangerous in this respect; in general it is preferable to avoid having any highly resonant circuits in the intermediate frequency amplifier.

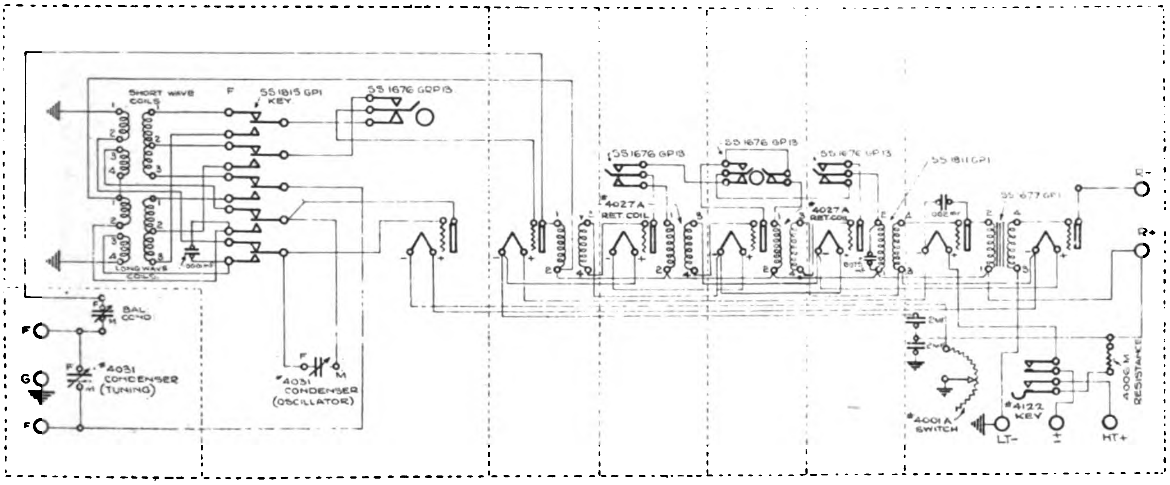


Figure 11—Schematic of the No. 4002 Radio Receiving Set.

The choice of a suitable value for the intermediate frequency is governed by a number of considerations. The lower limit is implied in the name "supersonic"; so far as the human ear is concerned, anything above 30,000 cycles per second can be considered as supersonic, which, when allowance is made for tone modulation up to 5000 cycles, gives a lower limit of 35,000 cycles per second for the carrier frequency for which the amplifier should be designed. If instead of the human ear, the limit of audible frequency be based on the characteristics of existing sound reproducers, we may safely choose a frequency somewhere about 10,000, giving a lower limit of 15,000 cycles for the intermediate frequency. The upper limit is, of course, fixed by the lowest carrier frequency which will be received. Within these limits, the design of the amplifier is favoured by keeping the intermediate frequency low inasmuch as the effect of valve inter-electrode capacity giving rise to coupling between the input and output circuits is thus reduced. Consequently, the amplification which can be employed without running into instability is increased and the shunting effect of small capacities is decreased, so that greater amplification per stage can be obtained. From the operating standpoint, however, the highest possible value of intermediate frequency is favoured. It has been remarked in connection with the reception of any particular wave length that either of two oscillator (local carrier) frequencies may be used to convert the signal carrier to the required intermediate frequency. It follows that for any particular setting of the oscillator there are two incoming frequencies, both of which will be converted to the same intermediate frequency automatically. The difference in signal strengths given by the two carriers will depend on their relative amplitude, and it is evident that if the aerial circuit is tuned to one of the carriers, a signal of the other carrier frequency will result in reduced interference in proportion as its frequency is separated from that of the tuning adjustment in use in the aerial circuit. This type of interference is peculiar to supersonic reception. Since the separation of the carriers which will give rise to this double channel is twice the intermediate frequency, it is obviously desirable that the latter be as high as possible so that the maximum attenuation of the interfering carrier will occur before it reaches the frequency changing detector. A further advantage in using a high intermediate frequency is that valve noise in the amplifier generally is somewhat less than with lower frequencies. The designer, therefore, must compromise between these conflicting requirements and select a valve for the intermediate frequency which will give good stability and high gain in the amplifier, and yet avoid any serious double channel interference.

Supersonic Receiving Sets

Since the supersonic receiving set is of outstanding interest and importance, it seems desirable by way of illustration to consider in some detail the design of the No. 4002 Set. The circuit schematic is shown in Figure 11 and the set itself, together with its associated equipment, in Figures 12 to 14, inclusive. It is intended for use in conjunction with the No. 4001 Frame Aerial, and employs seven valves of the peanut type, the filaments of which are connected in series. Three stages of intermediate frequency amplification are provided, one, two, or three stages of amplification being cut in as required by means of vertical type keys. Transformer coupling is used between the stages, the transformers having iron cores of the shell type, mounted in metallic screening cases. Owing to the inherent capacity of the windings, the transformers operate as though partially tuned, and are designed to give maximum amplification at the frequency of approximately 45,000, which has been chosen as the most convenient value for the intermediate frequency, bearing in mind that the set is intended for use on wave lengths up to 3000 metres (frequency 100,000 cycles). Between the intermediate frequency amplifier proper and the last detector, is a filter coupling using an air core transformer tuned by an external condenser. In conjunction with the partial tuning of the interstage coupling transformers, this filter determines the frequency pass band and hence the selectivity of the amplification system, while the tuned frame aerial gives a further degree of selectivity independent of the amplifier. One valve is allotted the special function of generating the local e.m.f. required for the frequency conversion, while another valve

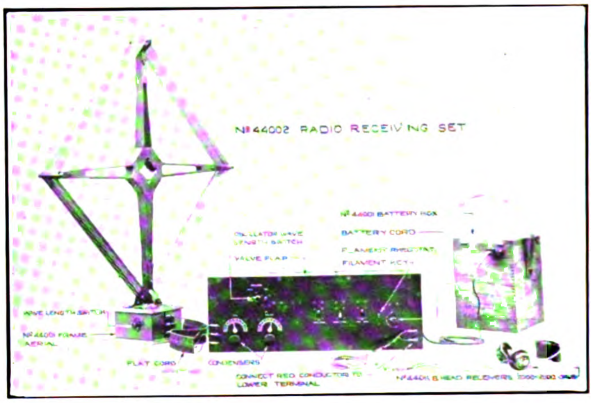


Figure 12—No. 4002 Receiving Equipment Complete with Frame Aerial and Battery Box.

is used as a first detector to give the intermediate frequency wave. It is possible to combine the two functions in one valve, thereby gaining a slight economy, but this arrangement usually makes necessary very careful choice of the valve if efficient operation is to be retained, and may result in a loss of selectivity due to the generation of rather strong harmonics in the oscillator.

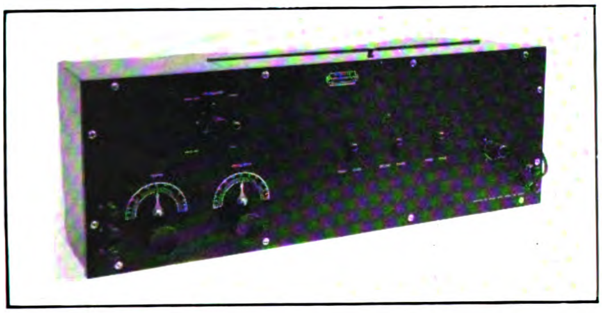


Figure 13—No. 4002 Receiving Set—Front View.

The local e.m.f. is applied to the first detector of the set by induction into a coil which is in series with the grid of the detector and which does not form part of the frame aerial tuning circuit; in this way the load on the oscillator and hence the magnitude of the local e.m.f. is kept approximately constant independent of variations in the tuning of the frame aerial. At the same time there is little risk of the frame aerial circuit being pulled into step with the local oscillator and acting as a radiation circuit. Both detectors operate on curvature of the anode characteristic with large negative grid bias, so as to reduce the risk of overloading. The appropriate grid bias for any valve is obtained by using the voltage drop across the other filaments. From Figure 14, it will be noted that shielding is extensively employed; the frame aerial tuning circuit, the oscillator circuit, and each stage of intermediate frequency amplification are individually shielded, while the last detector and the stage of L.F. amplification occupy a common shielded compartment. The D.C. feed circuits —filament, grid and plate—are cable formed, while any leads which are at high frequency potential to the battery system are run separately. Since either one, two or three stages of intermediate frequency amplification can be used according to the setting of the keys, a range of amplification is provided sufficient to enable the set to be used with equal efficiency on either local or distant stations.

It will be seen from the foregoing that the design of a radio receiving set which will meet modern demands as to sensitivity and selectivity and at the same time deliver to the audio reproducing system an input substantially similar to that broadcast by the transmitting station, and also retain ease of control, is by no means easy.

Loud Speaker Operation

The better class of radio receivers generally are used under conditions where loud speaker operation is desired. For this purpose an audio frequency amplifier should be provided which is capable of delivering to the loud speaker an undistorted signal energy of not less than .05 watts and preferably about .25 watts. The power output of the majority of detectors available for ordinary use is considerably below these values, being of the order of .00005 watts when operating just below the overload point. It is, therefore, generally necessary that the detector be followed by one or two stages of audio frequency amplification having a gain of at least 30 TU and that this gain be constant over the frequency range essential for the undistorted reproduction of high quality musical programs. The production of such an amplification system is in itself no mean problem and while, strictly speaking, not part of the radio design, it must nevertheless be considered in relation thereto. Its study is not, however, within the scope of this paper, except for the determination as above of the required gain and output level.

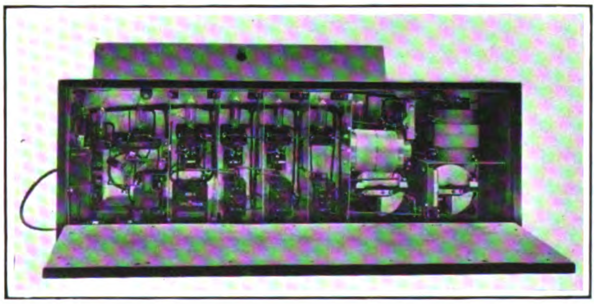


Figure 14—No. 4002 Receiving Set—Rear View.

Electrical Communication and Progress in the Irish Free State

By L. J. KEOGH

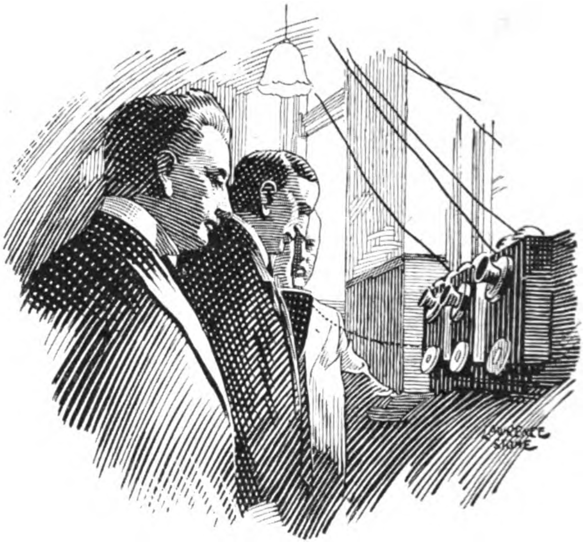
Standard Telephones and Cables, Ltd.

Progress in Telephony

WHEN Southern Ireland obtained Dominion status, the new Irish Government realised the need of an efficient up-to-date telephone service. As soon as the necessary funds had been placed at the disposal of the Telephone Administration, engineering and stores headquarters were organised, and a small factory was equipped in Dublin to handle repairs and assembly. The work of making good the plant, both internal and external, which had been destroyed during the troublous times, was in itself a great undertaking; but while this was being effected, future development was well in view, and extensive line work was carried out as indicated on the accompanying map. New districts were opened up, particularly in the North West, and communication by means of radio telephony was established between the more important islands off the west coast and the mainland. People who had been completely isolated were enabled easily to get into touch with their fellow countrymen at any time.

The lines between Dublin and Limerick, Cork, Waterford and many other important centres were in an imperfect condition, but the new Administration reorganised all the existing lines and furnished additional channels wherever it seemed necessary. Underground networks and distributions in city areas also needed overhauling, and extensive alterations were necessary. To effect these changes a substantial contract for twelve months' work was placed with Standard Telephones and Cables, Ltd., London, covering the supplying, laying and jointing required in the city of Dublin itself, and in the metropolitan area, as well as in Limerick and Cork.

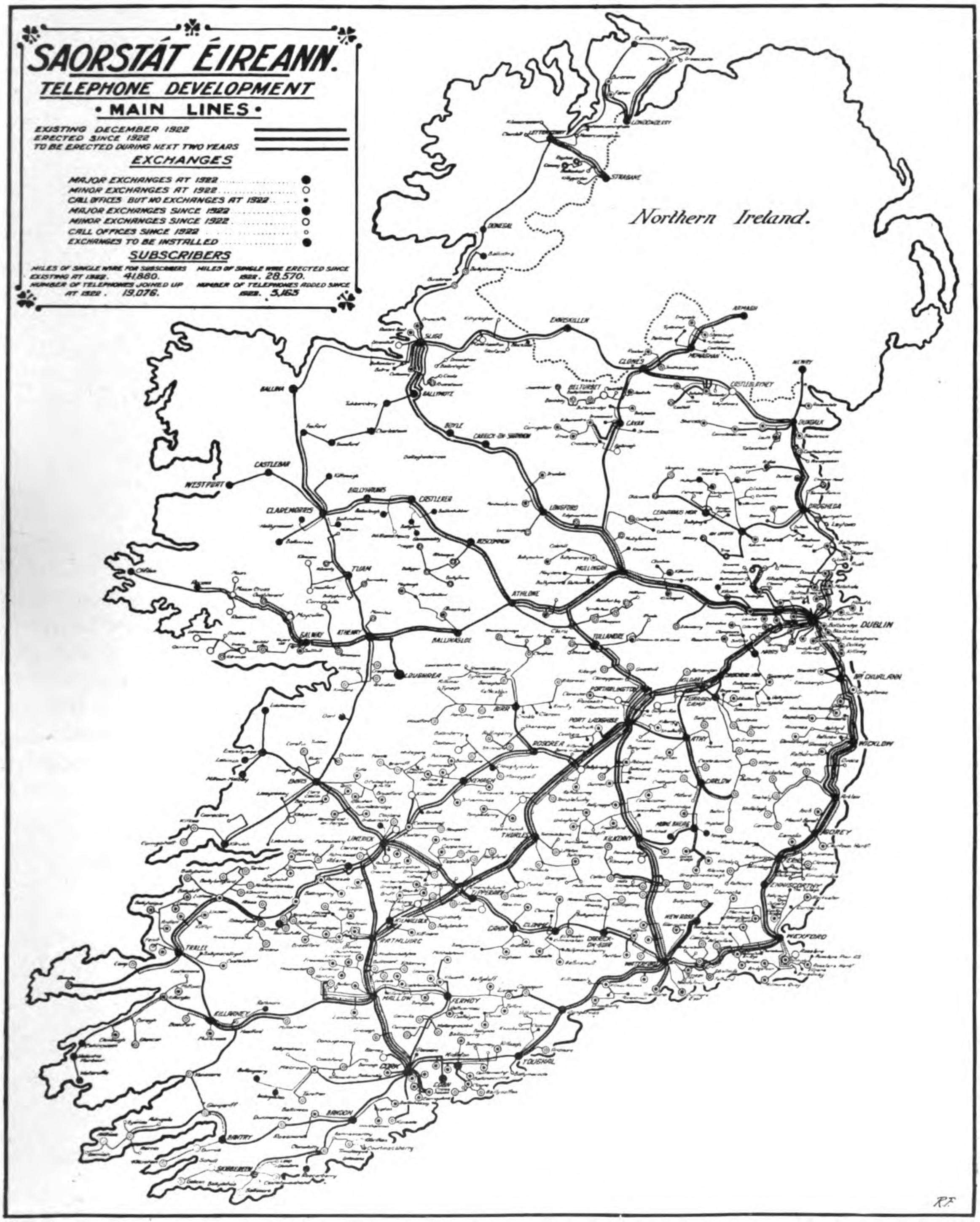
For the Dublin area, an automatic programme was chosen, and it was decided to adopt the step-by-step system, such as was being installed by the British Post Office in provincial areas. As a temporary measure, manual exchanges were installed to relieve the situation in Dublin. The existing main exchanges, Crown Alley, Rathmines, Clontarf—all local battery magneto-calling types—were seriously congested. The only comparatively modern exchange was Ballsbridge, which is a central battery type. It is unnecessary to lay stress upon the fact that the first automatic exchanges were far from presenting a straightforward engineering proposition.



Visit to Ship Street Automatic Exchange of Cabinet Ministers, showing Mr. J. J. Walsh, Minister for Posts and Telegraphs, initiating first call, Mr. Cosgrave, the President, and Mr. P. Mulligan, the Irish Engineer-in-Chief

A contract was placed with the Standard Company for two new Dublin exchanges—Ship Street (1,600 lines) and Merrion (2,000 lines)—to replace the two temporary manual relief exchanges mentioned above. The Ship Street equipment was the first step-by-step apparatus manufactured at the Hendon works of the Standard Company.

The opening of the Ship Street exchange, the first automatic exchange in the Irish Free State, was an event of special importance, marking a step in the development of automatic telephony



Map of Ireland Showing Telephone Development in the Irish Free State.

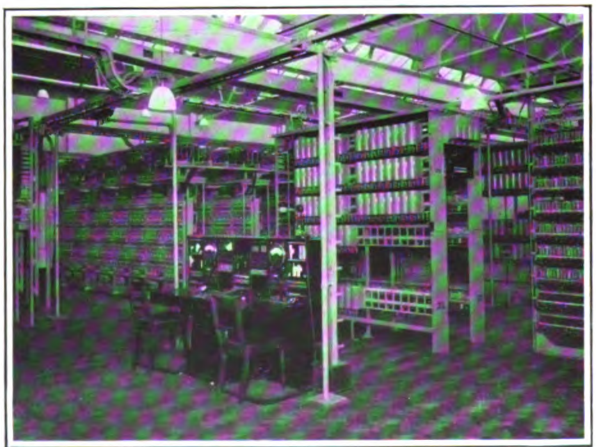
in Ireland. The exchange was cut over on July 24, 1927, and in spite of the difficulties involved in arranging junction working with apparatus of the former systems, the cutover was very satisfactory and no appreciable inconvenience or delay to subscribers was involved. The second automatic exchange, Merrion, with a total equipment of 2,000 lines was cut over on December 10, 1927, with equal success.

Such energetic steps generally were taken by the State Engineer and his representatives that most of the arrears have now been wiped off, a highly skilled staff has been trained, and telephonic service throughout the State has been placed on a very sound footing.

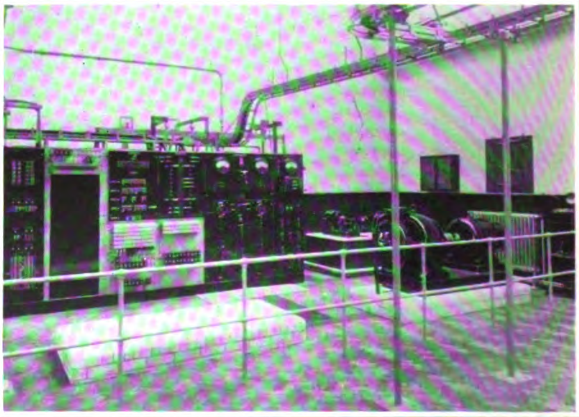
Mr. O'Neil, Staff Engineer in Charge of Automatic Plant, in a Jaunting Car.

Broadcasting

The revenue for the broadcasting service is obtained by the Department of Posts and Telegraphs by the levying of a license of 10/-per set and by a duty of 33.1/3 percent on all radio apparatus and components thereof imported, irrespective of country of origin.



Automatic Equipment and Test Desk* for Merrion Exchange.



Power Plant * for Merrion Exchange.

The two broadcasting stations which have been put into operation by the Free State Government are situated respectively in Dublin and in Cork. The latter is a 1.5 KW (Geneva rating) transmitter, designed and built at the Hendon Works of the Standard Telephones and Cables, Ltd., London. The station is located at Sunday's Well, a suburb of Cork, and is housed in what was the female prison for the district. The station serves Cork, the second city of the State, and also the thickly populated area of County Cork—in all, a population of about 400,000. Special features in the radio transmitter are the use of a very stable master oscillator for generating the carrier frequency, and modulation at low power level followed by amplification of the modulated carrier up to the required aerial power. Push-button starting is provided—the operation of a single press button starting or stopping the whole transmitter.

The Department of Posts and Telegraphs constructed the aerial and earth system, which was designed by the Standard Company's engineers. An inverted "L" type aerial is employed, consisting of four spans, each 156 feet in length, the masts being of wood 120 feet in height. The aerial is capacitatively coupled, and facilities are provided for using either a buried earth system or an insulated counterpoise. The earth system consists of an earth mat composed of 7/22's S. W. G. copper, covering an area of approximately 20,000 square feet.

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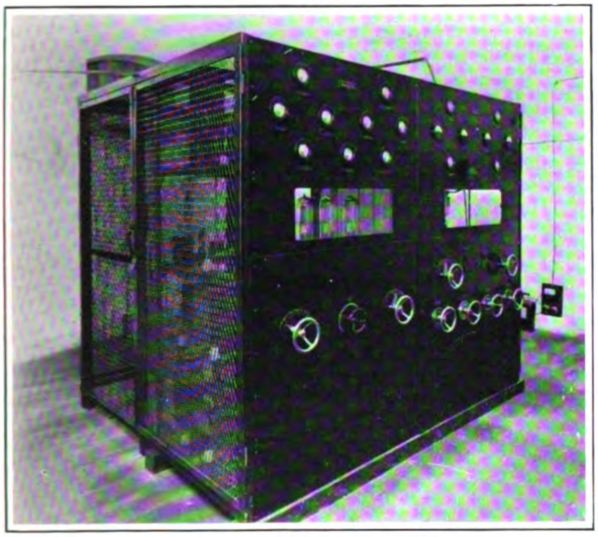
* Photograph of equipment as set up at the factory before installation.



1.5 KW (Geneva Rating) Radio Broadcasting Transmitter at Cork Broadcasting Station.

The Administration is at present considering the installation of a high-power station to afford crystal reception to the people in the Irish Midlands and West of the State.

Communication Projects Completed 1922–1927

During the period 1922–1927, the following work was brought to completion:

New Exchanges Opened	Manual	297
	Automatic	2
Miles of Conduit Laid		151
Miles of Cable Laid		146
Distributing Points Opened		1,170
Miles of Open Wire Trunk Line Run		3,443
Broadcasting Stations Opened		2

The Department of Posts and Telegraphs maintains the electrical control and communication lines of the railways throughout the State.

At present the Department operates:

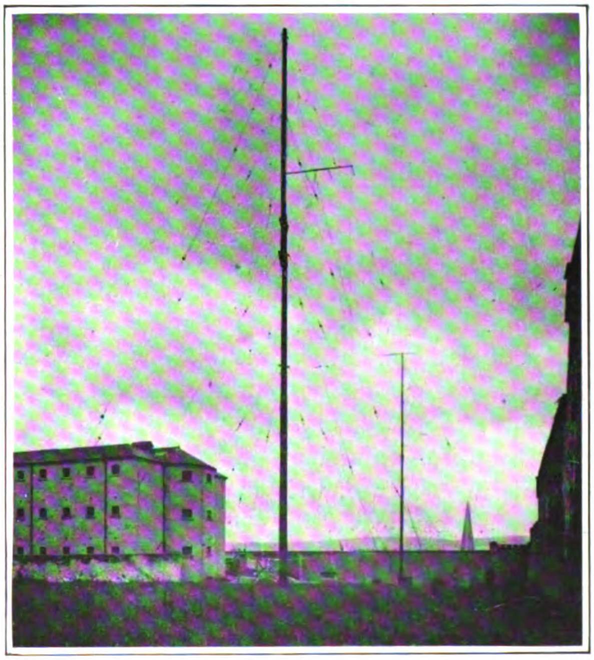
Exchanges	520
Call Offices	1,005
Exchange Stations	25,370

The annual increase in total stations is 2.1 percent.

General Progress

Since the Free State took control, excellent work has been done generally. Buildings destroyed during the period of trouble have been rapidly rebuilt, and there is now little evidence of those days. Extensive road work has been carried out, so that all trunk and important roads are now in first-class order. An ambitious hydro-electric scheme to provide electricity from the River Shannon, has been initiated and the work is now well in hand. Beet sugar factories have been opened, and considerable work has been successfully undertaken to educate the Irish dairy farmer in the scientific marketing of his main products, butter, eggs, etc.

It is doubtful if the charms of Ireland are sufficiently known. Quiet and pretty seaside villages are to be found every few miles on every coast. To those who appreciate natural scenery of great beauty and diversity, the whole



L-type Aerial at Cork Broadcasting Station.

of the country with its mountains and lakes must appeal. The sportsman finds in all parts, excellent fishing, shooting and hunting. The resident in, or visitor to, Dublin, within a few minutes of the centre of the city, is excellently provided for at small cost, with golf, tennis, swimming, rowing, yachting or with practically any other form of sport or open air pastime.

The whole country abounds in archæological remains, and within easy reach of Dublin there are many spots that will afford pleasure to the explorer.

The visitor to Ireland, of course, finds much of historical interest, and in Dublin can visit Trinity College, St. Patrick's Cathedral, Christ Church, the Old Houses of Parliament and many other notable monuments. The famous library of the university contains amongst other treasures, the "Book of Kells," probably the most beautifully illuminated manuscripts of the Gospels in existence, written in half-uncials of the seventh century.

Glengarriff Bay, County Cork.

No words on the subject of Ireland would be complete without mention of the Dublin Horse Show. This is the chief annual event organised by that enterprising body, the Royal Dublin Society, and except for the industrial section, it is restricted to horses, including the heavy dray horse as well as valuable thoroughbreds and hunters. Apart from the show itself, this is the main social event of the year; Dublin and district is "en fete" for the week, buyers of horses and hunting people from almost all parts of the world foregather in Dublin, making the show a spectacle that is unique and one that has to be seen to be appreciated.

Royal Dublin Horse Show—1927.

In some remote parts of Ireland, there are still people whose only language is Gaelic, and in the rural areas generally the traditional Irish dancing and music prevail. The Irish Government are now taking energetic steps to encourage and foster the native tongue as well as the national culture in music and literature. The ass and flat cart are still the standard means of

Royal Dublin Horse Show. International jumping competition. A Swiss officer jumping.

conveyance employed by the peasant for taking the daily yield from his cows to the neighbouring creamery, where it is made into butter and cheese. The cattle and horse fair remains a feature of country life, and the drover in many cases takes his herd of cattle great distances, often starting the night before the fair in order to arrive in time to dispose of it there.

The Irishman still uses the picturesque side or jaunting car, although within the last two years or so, this characteristic vehicle has been seriously challenged by the taxicab.

Glendalough, County Wicklow.

Australia First to Use Type C-2-F Carrier System

Long Haul Single Channel Carrier Telephone Systems Connect Melbourne with Important Farming Centres in Victoria and South Australia

By J. S. JAMMER

Carrier Engineer, International Standard Electric Corporation

THE installation of two Type C-2-F Single Channel Carrier Systems has completed another link in Australia's enormous trunk line network. This marks a further step toward the Telephone Administration's goal, which is to provide a highly efficient, nation-wide telephone service. The magnitude of such an undertaking may be more readily appreciated if it is recalled that Australia covers an area twenty-five times as great as that of England, with a total population less than that of the city of London. In line with the progressive policy characteristic of their nation, the Australians were quick to appreciate the advantages of carrier and promptly adopted this method of economically providing high grade communication channels.[1]

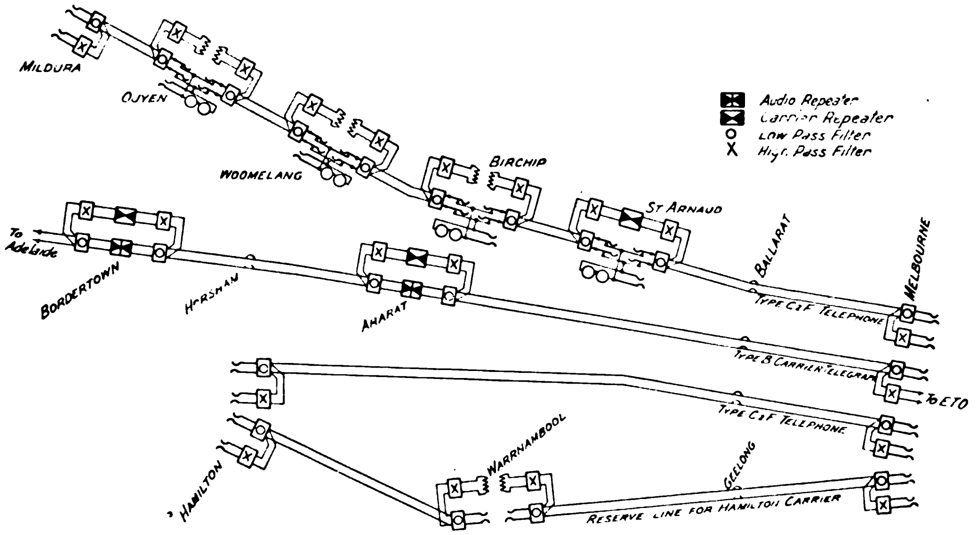


Figure 1—Schematic of Carrier Circuits in Victoria.

These two single channel installations are of particular interest because they are the first systems of this type to be installed, and because they are an actual working application of the scheme of using long haul single channel carrier circuits as forerunners to multi-channel systems to relieve traffic congestion and to improve transmission on "omnibus" and other circuits.

In providing trunk line facilities in a sparsely populated district the traffic requirements, as a rule, are such as to necessitate the use of omnibus circuits. This must be done in order to provide service to the way stations until such time as the traffic justifies the provision of a traffic distributing centre. For heavily loaded lines, the omnibus method of operation is not efficient from a traffic standpoint; and as stations are added and the line extended, the transmission to the more remote stations becomes unsatisfactory. Because of the unstable impedance of omnibus circuits, telephone repeaters cannot be used to improve the transmission. Thus, we are forced ultimately to provide high grade channels to a distant traffic distributing centre, and it is in such cases that the Type C-2-F Carrier System proves of considerable advantage.

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[1] "Why Australia Adopted the Carrier Current System," J. S. Jammer, *International Telephone Review*, Vol. IV, No. 3, July 1928.

There exists in the western portion of Victoria, and the southeastern portion of South Australia, a tremendous farming district which has a large community of interest with Melbourne—the important seaport and financial centre of southeastern Australia. This is one of the oldest cultivated districts in Australia, work in the region having begun over one hundred years ago. Hamilton, a prosperous country town with a population of about 5,000, is the logical traffic centre for telephone and telegraph communication from Melbourne to this important farming district.

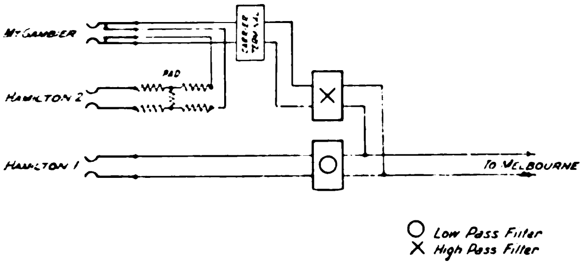

Figure 2—Switching Arrangements at Hamilton.

Before the advent of carrier between Melbourne and Hamilton—a distance of 168 miles—there existed but one 200 pound non-repeatered physical circuit, which gave a transmission equivalent of about 12 TU. Feeder lines extend from Hamilton up to a distance of one hundred miles, the longest of these extensions being to an important tourist district known as Mount Gambier, in South Australia. The increasing demand for an improved telephone service in this region caused the Australian Administration to consider seriously the erection of a new physical circuit which would be of such grade as to provide good transmission from Mount Gambier to Melbourne; but, when the full advantages of the Type C-2-F System were realised, this means providing a new circuit was immediately adopted. The carrier system was installed between Melbourne and Hamilton, and normally operates on the Melbourne-Hamilton physical circuit with an alternative route through Geelong and Warrnambool, as indicated in Figure 1. By providing carrier transfer filters at Warrnambool, two separate high frequency circuits are made available; and, as these are not on the same pole route, continuous service to the Hamilton district is ensured.

In order to give an 8 TU equivalent from Mount Gambier to Melbourne, the carrier channel is worked at a 4 TU gain from Melbourne to Hamilton. This with the 12 TU loss which exists in the line between Hamilton and Mount Gambier, gives a net loss of 8 TU from Mount Gambier to Melbourne. The circuit can be extended to Sydney on a Sydney-Melbourne carrier channel working at a 3 TU equivalent, thus giving Mount Gambier an 11 TU circuit to Sydney—a distance of over 1,000 miles.

In order that the carrier system will not be overloaded when the circuit is used for Hamilton business, an 8 TU pad is inserted in the low frequency circuit for Hamilton connections. This pad is automatically cut out when the circuit is switched through to Mount Gambier. A simple diagram of this arrangement is shown in Figure 2.

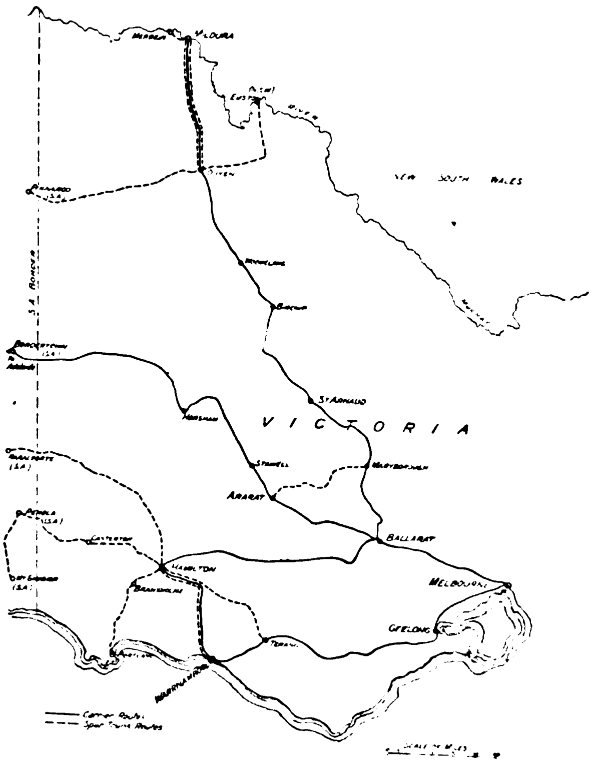

Figure 3—Map of Centres Served by the Type C-2-F Carrier System.

Other important centres which are switched at Hamilton for connection with Melbourne, Sydney and Adelaide, are Branxholme, Portland, Casterton, Penola and Naracoorte. The relative location of these centres and the two routes from Melbourne to Hamilton are shown on the map, Figure 3.

The northwestern district of Victoria—the Mallee district—is a very fertile region, the principal products being fruit and wheat. This fruit area has given rise to the dried fruits industry, which recently has been stimulated by the Government's assigning tracts of land to returned soldiers. The centre of this rich and fertile district is Mildura, and, here again, we find the clearing house for the commercial activities in the district is the traffic centre for the communication system.

A great deal could be written about the romantic history of Mildura, the centre of a district which, by modern irrigation methods, practically was converted from a desert into a profitable farming district.

Mildura is first noted in history in 1846 when the district was a cattle run, known as Tretman. For a number of years this area was considered to be of so little value that the cattle owners did not bother to register their holdings. In 1886 the Chaffey Brothers, who were engaged in promoting irrigation settlements in California, learned that cheap land, suitable for irrigation, might be had in Australia. They investigated the matter, and, after analysing the soil, appreciated that water was the only thing required to convert this district into flourishing farms and vineyards, whereupon a company was formed which entered into an agreement with the Australian Government to undertake the irrigation.

When the Chaffey Brothers obtained possession of this district they set apart an area, which is now called Mildura, as the centre of the colony. By 1890 the population of Mildura had grown to 2,000, and the thousands of acres had been split into orchards producing grapes, oranges, lemons, peaches and figs.

As the district improved it was appreciated that some transportation facilities would be required and eventually the Government built a railway line from Melbourne; this was opened on 13th November, 1903. Year after year the production increased and in 1911 the population reached 6,000; however, the greatest extension came during the World War when Turkey and Greece, two of the principal dried fruit producing countries of the world, were forced to cut down their production.

The first soldier settlements in the district were established in 1917, and in 1920 Mildura reached the height of its triumph. The products were bringing tremendously high prices and there was a great deal of trading in land blocks, but in 1923 there was a big slump in the dried fruit market and the district got its most severe setback. The Australian Government, recognising a crisis in the industry, made an effort to stabilise prices and assisted in the effective distribution of the product. This period of depression has been overcome and the district is again becoming more prosperous; it is expected that the coming year will show a marked advance.

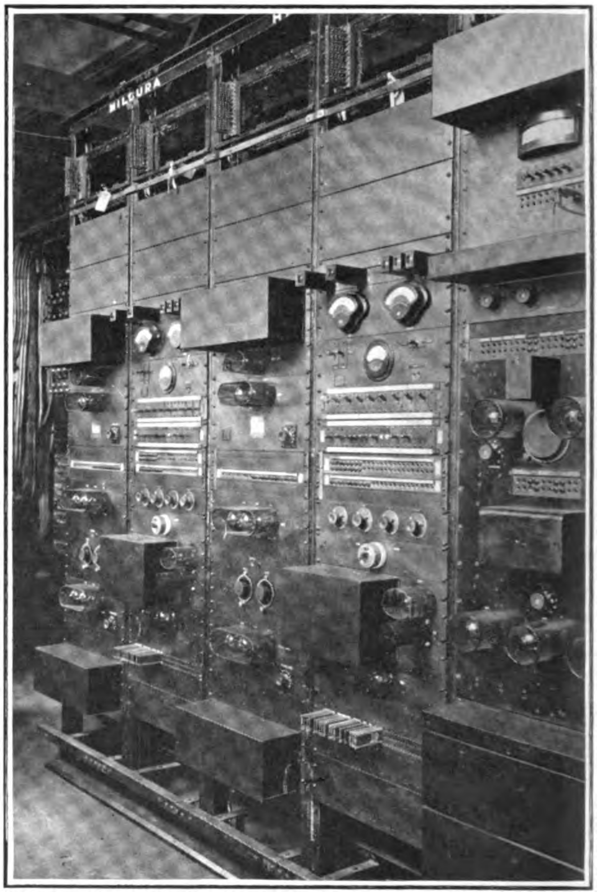

Figure 4—C-2-F Carrier Terminals in the Melbourne Office. The two bays shown at the left are the Mildura system and the next two bays, the Hamilton system. The single bay at the right is one of the bays of the Sydney-Melbourne three channel carrier system.

Before the carrier equipment was installed there existed one physical telephone circuit from Melbourne, through Ballarat, St. Arnaud, to Mildura—a distance of 360 miles. This was an omnibus circuit, with a number of stations bridged across the line at intermediate points. In order to relieve the traffic congestion on the through Mildura business and to provide better transmission to the more remote way-stations, it was decided to install a Type C-2-F System on this route. Figure 1 shows a line diagram with the carrier repeater at St. Arnaud, and carrier transfer filters at Birchip, Woomelang and Ouyen.

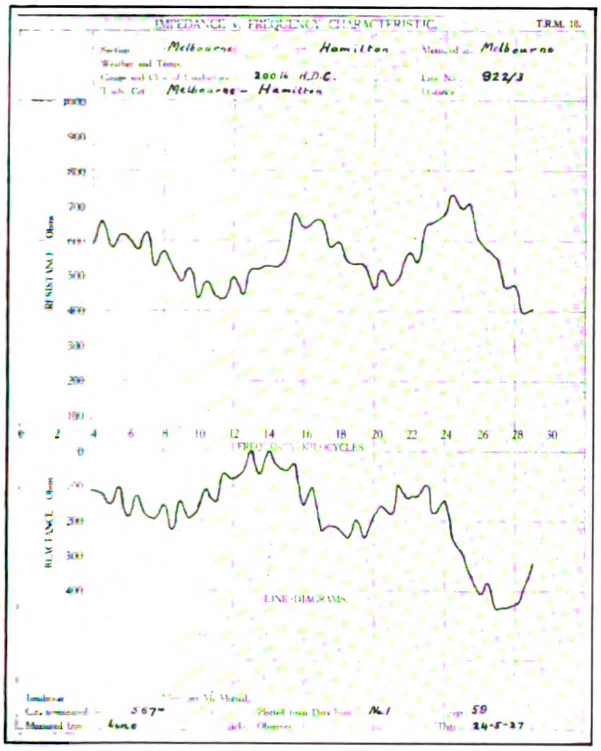

Figure 5—Impedance-Frequency Characteristics of the Melbourne-Hamilton Circuit Measured from the Melbourne Terminal.

The low frequency equivalent of the physical circuit from Melbourne to Mildura was about 16 TU. Now that the carrier is installed, the physical circuit is broken at Birchip, which provides any station on the Melbourne side with an equivalent of not more than 12 TU. The carrier channel itself is set up to operate at a zero equivalent from Melbourne to Mildura, so that subscribers beyond Birchip are actually connected to Melbourne through Mildura. In other words, the Melbourne subscriber talks over the carrier all the way to Mildura, and then back over the physical circuit to the intermediate stations as far back as Birchip. The low frequency equivalent by this path to Birchip is 7 TU. As indicated in Figure 3, the important centres of Euston, Merbein, and Pinnaroo, feed into this line.

Figure 4 shows the two terminals in the Melbourne Office, the two bays on the extreme left being the Mildura system and the next two bays, the Hamilton system. The one bay on the extreme right is one of the channels of the Sydney-Melbourne system [2] which was installed in 1925.

Before the carrier systems were installed high frequency line measurements were made to make sure that the circuits would be suitable for carrier operation and to locate any line irregularities. Impedance measurements are a fair criterion of

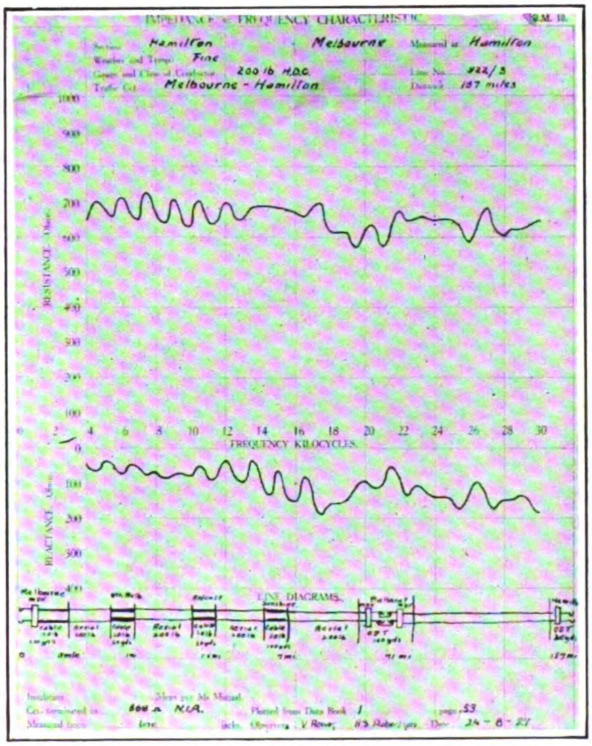

Figure 6—Impedance-Frequency Characteristics of the Melbourne-Hamilton Circuit Measured from the Hamilton Terminal.

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[2] "Carrier Telephone System Installed Between Sydney and Melbourne," Francis A. Hubbard, Electrical Communication, Vol. IV, No. 3, January 1926.

the line characteristics, and the measurements made on these circuits are shown in Figures 5 to 9.

Figures 5 and 6 show the impedance of the Melbourne-Hamilton circuit, measured first from the Melbourne terminal and then from the Hamilton terminal. The line shows some distortion in the impedance characteristics when looked at from the Melbourne terminal, but over the range of the C-2-F System, that is, up to 10,000 cycles, is good enough for carrier operation. This system, therefore, was put into service without any changes in the line whatever. Similarly, no changes in the Melbourne-St. Arnaud section of the Melbourne-Mildura line were required.

Measurements of the St. Arnaud-Mildura section of the line, however, indicated a serious distortion in the impedance characteristic, as shown on Figures 7 and 8. The irregularity in the line causing this trouble was near the St. Arnaud Office, and it was for this reason that the measurements made from Mildura are much more satisfactory than those made from St. Arnaud. From the frequency interval between the peaks of the impedance characteristic it was possible to compute the distance of the line irregularity from the St. Arnaud Office; this trouble was removed, whereupon the line was satisfactory for carrier operation. The measurements of this section after the line had been cleared up are shown in Figure 9.

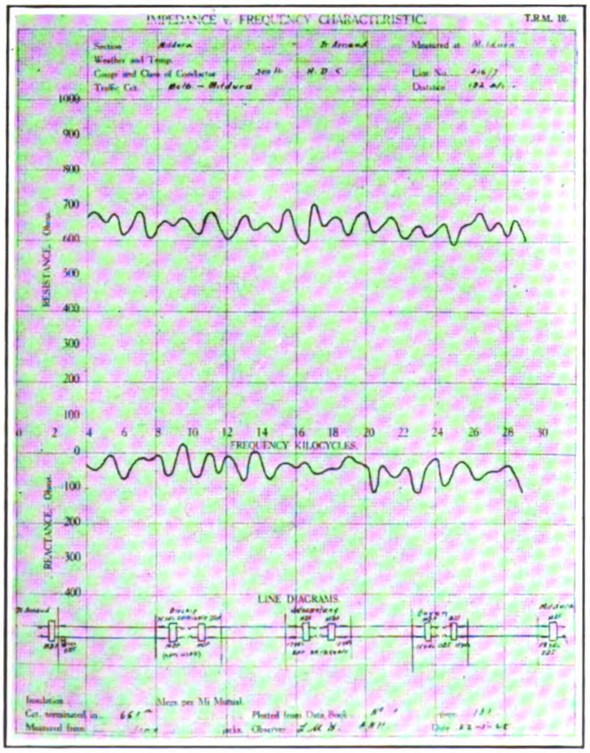


Figure 7—Impedance-Frequency Characteristics of the St. Arnaud-Mildura Section of the Line Measured from Mildura.

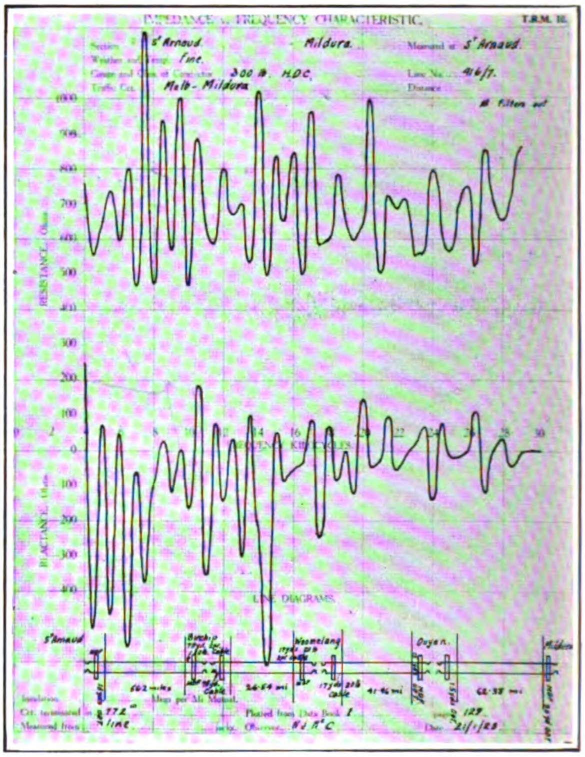


Figure 8—Impedance-Frequency Characteristics of the St. Arnaud-Mildura Section of the Line Measured from St. Arnaud.

There is one more interesting point in connection with these two installations, and that is the demonstration of the high degree of accuracy with which the carrier equipment is being produced.

The Melbourne-Hamilton system, which was the first ordered, was manufactured by the Western Electric Company, Inc., at Hawthorne (U. S. A.), and the Melbourne-Mildura system, the second ordered, was manufactured at the Hendon factory of Standard Telephones and Cables, Ltd., London. The American system was mounted on 6 foot 11 inch floor supported racks and the English equipment, on 8 foot 6 inch channel iron, ceiling supported racks.

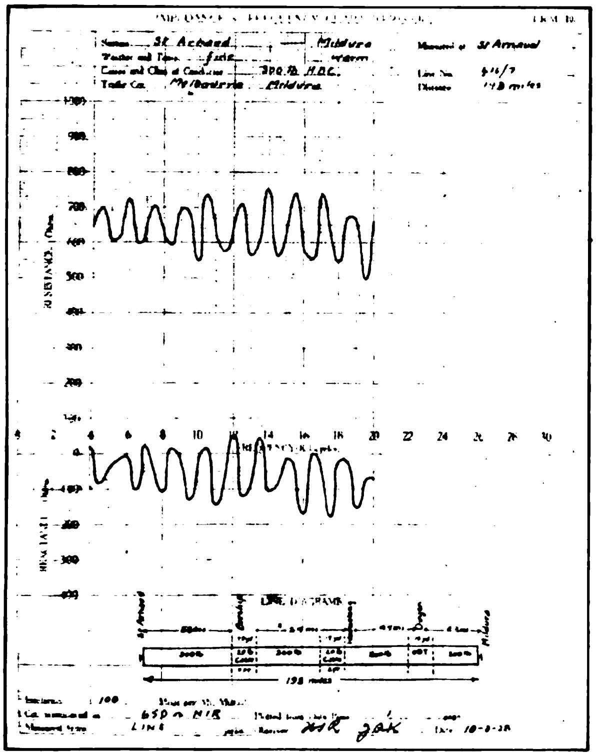


Figure 9—Impedance-Frequency Characteristics of the St. Arnaud-Mildura Section Measured from St. Arnaud after the Irregularity in the Line Was Removed.

The Australian Administration decided, for the sake of uniformity, to put all the London made equipment in the Melbourne Office, and to place one terminal of the Melbourne-Hamilton system at Hamilton and the other at Mildura.

It was realised that it might be necessary to interchange filters, as the band filters which are used with the C-2-F System are specially selected to work in pairs; however, the filter characteristics were measured, and it was found that all the filters involved were practically identical, so that the American equipment could be used on one end of a system and the London equipment on the other end without any modification whatever. Both these systems are giving perfectly satisfactory results in every respect.

It is indeed gratifying to observe the not unimportant contribution of the telephone towards the development of Australia—a nation which again proves to be a pioneer in the adoption of modern methods, in that it is the first to use the Type C-2-F Carrier System.

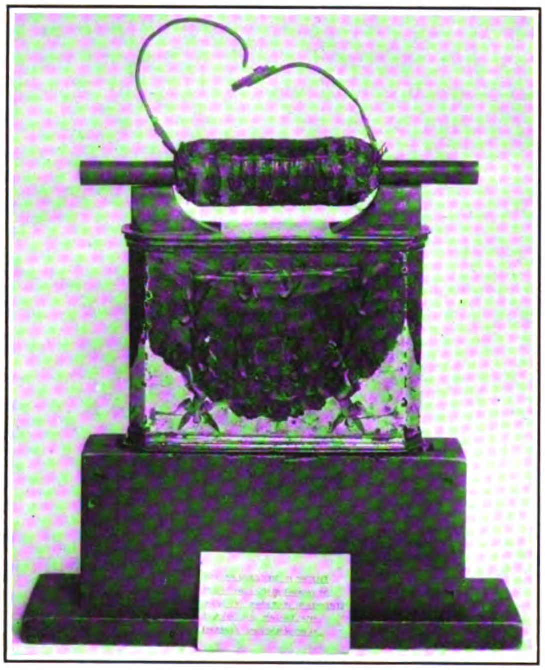
Acknowledgment

The writer wishes to acknowledge with thanks the kind assistance of Mr. N. J. McCay, of the Postmaster-General's Department; also of the Markets and Migration Commission of the Commonwealth of Australia, for the use of photographs.

A Famous Lodestone

The descriptive card reads: Russian Lodestone in Ancient Mounting Used by Faraday to Show the Induction of Currents by a Natural Magnet, and Faraday's Coil Used with It.

THE King George III Collection of apparatus at King's College, London, contains among other treasures the lodestone used by Faraday in his experiments on induced currents. This Collection consists primarily of the apparatus presented to King's College in 1841 by Queen Victoria. It was originally brought together by George III at the Royal Observatory, Kew. By the courtesy of the authorities at King's College the lodestone is illustrated in the accompanying figures.

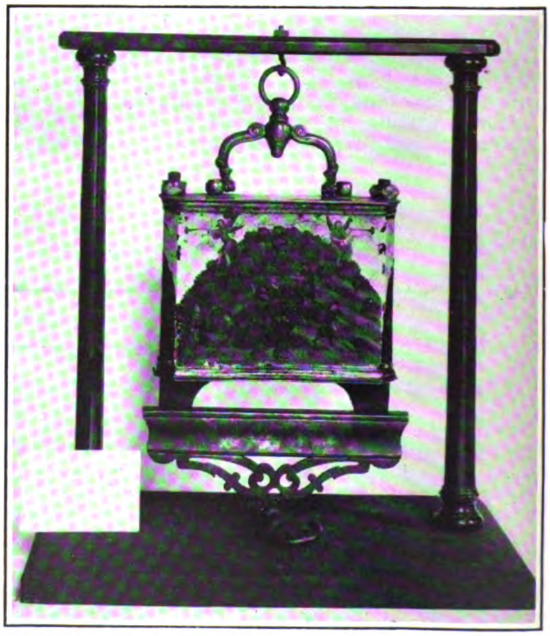


It is elaborately mounted, and of fine workmanship. On one side of the mounting is written in Russian the word, "Siberia," and on the other, the date, 1777. At the front is a coloured representation of two angels with trumpets, presiding over eight hard-working miners. At the back of the magnet is represented the same angels guarding only seven miners. The fate of the missing miner is not recorded.

Below the pictures is written in Russian, partly obliterated, a statement of the weight of the lodestone and the weight it is capable of sustaining. There is also a signature, W. W. Petroff 1803. An old notebook at King's College records the weight and the pull of the stone, but unfortunately the entries are based upon untrustworthy conversions. Today the weight of the lodestone with its mounting, but without the supports or the armature, is about 12 kilogrammes, and the pull is about 16 kilogrammes.

In Faraday's experiment the method of operation was to set the spark-gap of the coil to the required small length, and then to detach one end of the bar suddenly from its pole by a blow from the hand.

A detail of importance is to be observed at the spark-gap. The two bent conductors leading to the gap are of stout copper wire. One of these is filed to a blunt point. The other terminates in a copper disc upon the face of which is a removable zinc plate, fastened by a single screw. It is to be inferred that Faraday experimented upon sparks between various metals. The coil is protected by a leather covering that cannot be removed without injury to the relic; consequently the windings cannot be examined. Judging from the ends, where they are brought out, there appear to be several windings, possibly eight, in parallel. The principles of design of coils had not in those days been ascertained.



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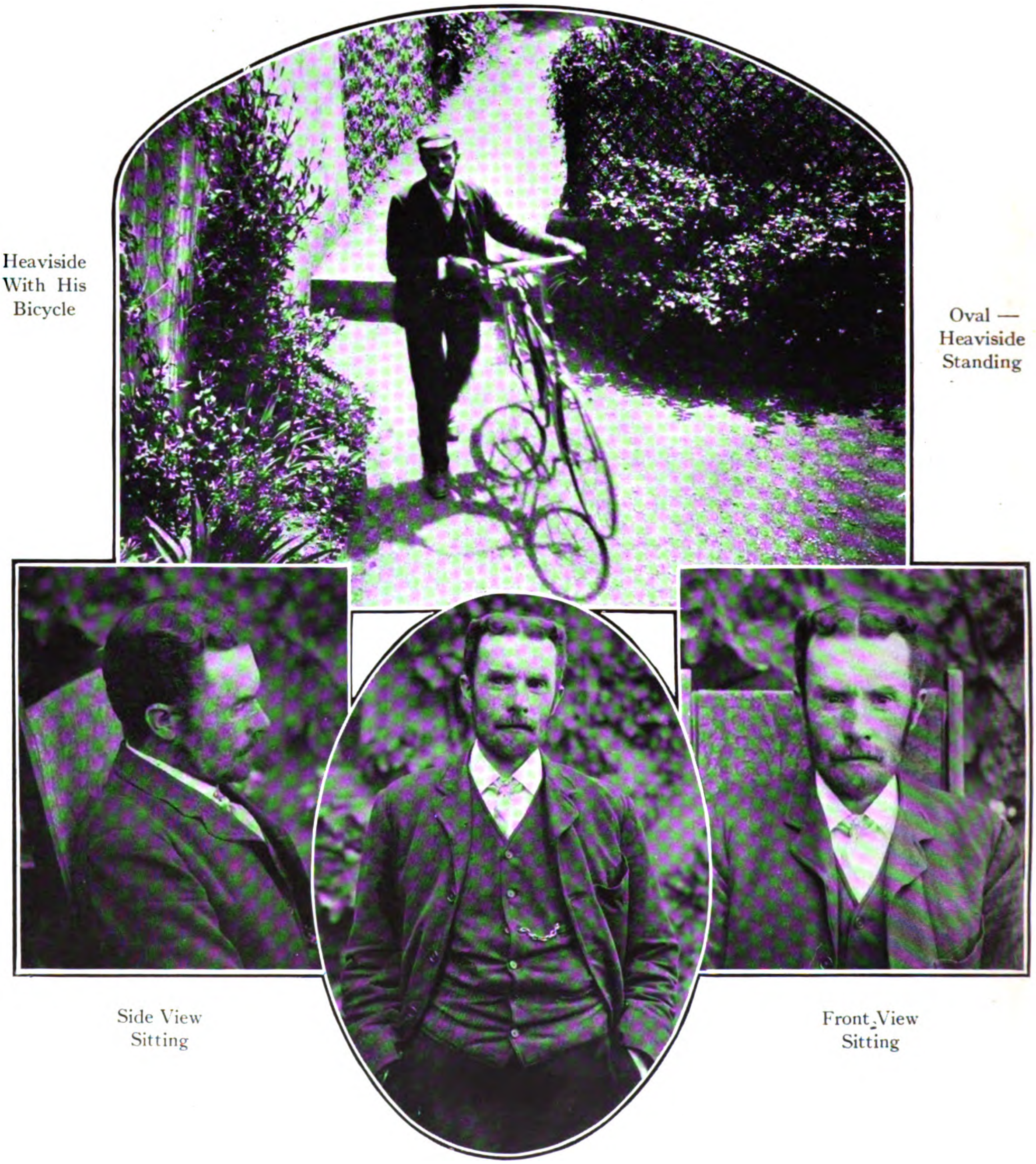


Heaviside With His Bicycle

Oval — Heaviside Standing

Side View Sitting

Front View Sitting

Oliver Heaviside

Pioneers of Electrical Communication

Oliver Heaviside—VIII

By ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

OLIVER HEAVISIDE, whose name a generation ago was synonymous with all that in the theory of telegraphy and telephony is most abstruse, is to-day acknowledged one of the most brilliant of the English pioneers of electrical communication. His discoveries and teachings provided the impetus that was needed to lift practice from the rut of contentedness with moderate achievement, and to render possible the establishment of a speech and signaling network to embrace the world. During a half-century of intense activity he wrote much. He survived to see his contributions collected, reprinted, and republished in volumes easily accessible. Those books will, for all time, relieve biographers from the task of recounting in detail the scientific and technical battles he fought and won. There is consequently freedom to dwell upon the story of his life, to indicate his relationship with his contemporaries, to glance at his correspondence, to penetrate into his character, to find if possible in what manner he acquired knowledge of mathematics and physics, and to account in some measure for his eccentricities.

His collected *Electrical Papers*, in two volumes, and his *Electromagnetic Theory*, in three volumes, form the chief portion of his contributions to mathematical physics in the particular territory where he ruled supreme. What is available in addition now includes certain of his manuscripts, mathematical notes and printed books, and a precious selection of his letters, recently acquired by the Library of the Institution of Electrical Engineers. Some of the notes were entered by him with scrupulous care in a series of manuscript books that must have occupied several years in preparation. Beyond the fact that the manuscript books bear marks that indicate that they were purchased in London, there is little to indicate where this mathematical work was done. At or near the time of his death, about fifty of his printed books by various authors, other than the books acquired by the Institution of Electrical Engineers, were sold and scattered.

Oliver's great-grandfather was George Heaviside, a northern English farmer, who married Elizabeth Winlow, of Dunston near Newcastle-on-Tyne. They had four sons, of whom Thomas, the fourth, was born on July 4, 1785, and died on April 1, 1859, aged 74 years. He was a builder and contractor at Stockton-on-Tees. He married Hannah Smith on January 22, 1809, who was born on December 26, 1787, and who died on January 27, 1852, aged 65. They had 13 children. Thomas, the father of Oliver, was the fourth. This Thomas Heaviside—who was born on October 6, 1813, and who died on November 16, 1896, aged 83—was a wood-engraver, draughtsman and painter in water colour. He married, on April 2, 1842, Rachael Elizabeth West, born December 17, 1818, died October 31, 1894, aged 76. She was the third child of John Hook West, of Taunton, Somerset, and of Hannah Bowditch, of that town. They also had four sons: Herbert Thomas (born December 31, 1842), Arthur West (born June 30, 1844), Charles (born November 13, 1846), and Oliver (born May 18, 1850). Oliver never married. Charles married; and the sister of his wife was Miss Way, of Homefield, Lower Warberry Road, Torquay, a good soul who for some years extended kindness to Oliver. Homefield was structurally altered in 1927–1928 and its name was then changed to Highwold. The Way family was related to the family of Bidder, the "calculating boy." An uncle of Oliver was Sir Charles Wheatstone (born 1802, died in Paris, October 19, 1875), who married on February 12, 1847, Emma West, the sister of Oliver's mother.

The facilities offered to printers by processes of photographic reproduction wrought havoc amongst wood-engravers, and it has been suggested that Thomas Heaviside, the father of Oliver, migrated to London to seek more remunerative means of livelihood.

To obtain particulars of the birthplace of Oliver, it has been necessary to search at the

General Register Office, Somerset House, London, and also to examine the archives at the Town Hall, Saint Pancras, London. The result is to discover that he was born at 55 King Street, Camden Town (Figure 1), and to confirm the date, May 18, 1850. The investigation has revealed that his father and mother became tenants there a few months after September, 1848, probably in 1849. They left this house at some time between 1862 and 1871. The rateable value of the house in 1850 was £35 a year. There is no doubt about the identity, for since the date of Oliver's birth, the numbering of the houses in that part of King Street has remained unaltered. That the work of Thomas was of a high order can be inferred from Figure 2, which is reproduced from an engraving by him of a drawing by Godwin. The inscription written by Oliver in the margin of the proof of this engraving throws light upon conditions at the time.

> "This was done in less than a fortnight (12 days, I think) under great pressure from Mr. Godwin when father . . . was very ill. £20, 1870. Franco-German war. (He asked £22.) Partly stress. Partly usual practice. Copy in bound volume also. Mr. Godwin had sole permission from Her Majesty to give a picture. Owing to these circumstances, was very proud of it, but it would have been better to have had time to finish it finer. O. H. But note in his book says fell ill October 15, whereas block is dated June 28. . . . There are four blocks down from October 8 to November 29 and Edwin was on all except first one."

The Edwin referred to was Edwin Heaviside, a wood-engraver, another brother of Thomas. In 1866, Edwin lived at 27 Fetter Lane, London.

An artist and engraver still more distinguished than Thomas or Edwin was their brother, John Smith Heaviside (sometimes Heavyside), whose name appears in Bryan's Dictionary and in Bénézit's Dictionaire, as a wood-engraver, in London and Oxford. He was born at Stockton-on-Tees on December 2, 1811, and he died at Kentish Town on October 3, 1864. A small portfolio, undated, now in the Library of the Institution of Electrical Engineers, has pencilled within it "J. S. Heaviside, 6, Belle Vue Cottages, Camden Street, Camden Town." His engravings enrich the writings on architecture of John Henry Parker. An example of his work is reproduced in Figure 3. The conclusion is inevitable that it was amidst the struggles and victories of art rather than those of science that the boyhood of Oliver was passed. There exist two of his sketches (Figures 4 and 5) that suggest that he had some early training and considerable skill in drawing. He has himself written under the first: "The Cart Horse. By Oliver Heaviside. Aged 11," and under the second: "2nd work by O. H. (No others preserved.)"

Positive evidence concerning Oliver's education is entirely lacking; there is a legend that he was at an early stage taught by his mother. In 1876 his father became the tenant of 3 Saint Augustine's Road, Camden Town, London, Figure 6. This house fortunately remains, and it has not been renumbered since 1866. It was owned by the Midland Railway Company. To make provision for widening, the neighbouring house was, some years ago, demolished. The rateable value of No. 3 in April, 1889, was £45 a year.

It is certain that from 1876 Oliver subjected himself to strenuous training. His habit was to retire to his room at about 10 o'clock at night and to work there until the early hours of the morning. He closed his door and windows, lighted his oil lamp, and allowed the air to become hot and stifling. He worked also during the day, in seclusion. In order that he might not be disturbed, his food was placed outside his door, and there it remained until he was disposed to take it. Thus he transgressed most of the rules that modern conventions prescribe for health. On the other hand, he enjoyed walking, and occasionally he had more vigorous exercise, for he was a good gymnast.

Amongst his loose papers is a list of gymnastic exercises, and there is also a list, prepared by himself, of measurements that related to him. The figures are here recorded. They are obviously to be interpreted as inches. The height is in agreement with what is remembered of him by a survivor of the family:

> "(1878.) Height 64½, leg 33, hips 34½, waist 28, chest 35 to 37 (latter under scapula), shoulder width 17, girth chest and arms 44, neck (smallest) 13, biceps 13, below elbow 11, wrist 6¼, hand 7, girth palm 8, foot 10, ankle (above) 7¾, calf 15¼, knee 12¼, thigh (groin) 21½, mid thigh 19½, round both knees 21½, mid thighs 31½, width hips 13, girth head (brows) 22, height of shoulder 54."

Briefly, he was a short, red-headed Englishman of autocratic disposition, and of superb powers of mental penetration and intuition, to which was added relentless scorn of masqueraders—some of whom he named the "scienticulists."

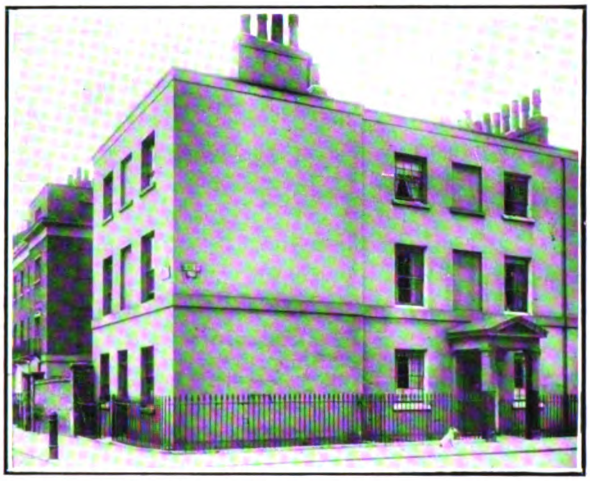


Figure 1—The House, 55 King Street, Camden Town, London, where Oliver Heaviside was born, and where he passed his boyhood. It is the one with the portico.

To account for his departures from convention, it is necessary to remember that he suffered from deafness. At rare moments his hearing was perfect, and he would then be the first amongst his youthful companions to detect the sound of a distant voice, or of the warbling of a skylark on the wing. Years afterwards, one of his manuscripts refers to similar temporary restoration, where he writes: "Episode in the struggle for life. Got rid of deafness partly. . . . Everything in this life that you want, comes too late." Also, he had little if any sense of smell. These defects had their mental counterparts in his qualities, for he became self-centered and possessed of suspicions that too often settled into more or less fixed prejudices. Happily, though his wit was acid and his satire occasionally ill-directed, he was blest with unfailing humour and a disposition that in the end prevailed upon him to forgive even his worst "enemy"—unfortunately then long dead.

In one of his letters to a friend, he speaks of music as having been one of his recreations:

> " . . . In old days I went to concerts, very long and highly classical; I always got wearied. I could not take it in—except the divine Shubert. Now there are a lot of very fine overtures of the Freischutz type. People hear them again and again, and so get to know them. May their performance be never discontinued.
>
> . . . I am very deaf. . . . I have no technical knowledge (of music) nor am I a pianist, though I once taught myself B's Opus 90. I liked it better than anything else. Truly the conflict between the intellect and the heart."

In those "old days" he also devised a musical notation intended to be easier to read than the orthodox system of lines, bars, and notes. Later he found some pleasure in playing an "Aeolian." The instrument he used still exists.

Only here and there is it possible to obtain a tangible clue to his personal history in his middle life. According to one account, after leaving school, he held a post with the Great Northern Telegraph Company, at Newcastle-on-Tyne. Positive proof of this has not been found amongst his papers. There is, however, a statement made by himself that he first observed a phenomenon relating to signaling through heterogeneous telegraph circuits at Fredericia, so that he evidently visited Denmark. From July, 1872, when he made his entry into technical and scientific literature, the surest guide to his career is his published work. An elder brother, Arthur West Heaviside, was a Divisional Engineer of the British General Post Office at Newcastle-on-Tyne. For a considerable period, Oliver worked closely with him, especially at solving such electrical problems as arose. There is a memorandum to the effect that on January 15, 1873—perhaps the happiest day of his existence—Oliver and Arthur made experiments "on duplex working with an artificial line and rough resistances at Beckett's shop." With single-needle instruments, they met with complete success "obviously to the delight of all parties." They proceeded to arrange a similar system between Newcastle and Sunderland. Messages were sent "simultaneously from both stations as fast as they could be transmitted by key." An entry in his note-book, relating to his paper in the *Philosophical Magazine* for June, 1873, states with satisfaction: "I was credited in America with having described quadruplex first, or suggesting it." His paper that followed it in the same journal in 1874, on the working of cables with condensers, was, he says, "the first that took terminal apparatus into account at all." In 1878 he directed attention to the importance of self-induction in telegraph instruments and telephones. Another glimpse of what he was doing is obtained from a draft agreement, dated September 14, 1880, relating to a patent for neutralising disturbances in cables. The next year there was a movement, on the part of his brother, to obtain for him other employment. At that time, the Chief of the Engineering Department of the British Post Office was William Preece—who was afterwards Sir William Preece. A letter to Oliver from Arthur explains what was in contemplation:

> "(November 22, 1881.) Preece states that the Western Union of America are about to adopt the Wheatstone, having ordered 24, and that he has the nomination of about six clerks to manage them, with salaries of about £250, and then he asked after you and I told him you were a student still—obvious—should you apply I believe he would nominate you."

What transpired is not recorded, but there is no doubt that, in June, 1882, this "student" was at 3 Saint Augustine's Road, experimenting at home with microphones, particularly to ascertain the effect of pressure at the contact surfaces. His apparatus consisted of a battery, carbon contact-blocks, a watch and a galvanometer. His note upon these experiments reveals him still an imp, and his father an experienced observer:

> "Father smells acid in the room. Two or three evenings. I said, at hazard, it was the electricity. Query, ozone generated by sparking, or nothing to do with it. Father says it is just like the battery he made when he was a boy, and that it is my battery. I didn't say it wasn't. What is the best arrangement to get the greatest variation of resistance in the circuit? I find that the internal and external resistance must be equal."

Among his smaller manuscript note-books now treasured in the Library of the Institution of Electrical Engineers is one that contains what he describes as "An abridged account of experiments in May, 1886, London." It relates to various arrangements of Wheatstone bridges, and it includes notes on condensers, telephones, galvanometers, relays, batteries, inductance balances, interference tests, lightning, and cohesion. He there refers to an experiment made by him as early as 1868. Another of these note-books gives an account of induction experiments carried out by him in July, 1883. The part he took in seeking for a "theoretical explanation" of the experiments carried out by his brother, A. W. Heaviside, in Newcastle, is alluded to in paragraph 216 of Vol. 1 of *Electromagnetic Theory*, and in *Electrical Papers*, Vol. 2, p. 323.

Referring to his paper in the *Philosophical Magazine* of November, 1886, he has an entry: "Most remarkable fact, was speaking by telephone between two circuits $\frac{1}{4}$ mile square, $\frac{1}{2}$ mile between centres."

It must always be regretted that circumstances so soon placed him out of direct touch with practical telegraphy and electrical apparatus; for his skill in experimental researches would inevitably have led to important developments. Moreover, in experiment, he would have found the natural antidote to ills consequent upon unremittant concentration upon theory.

At the prime of his life there was a dramatic change in his environment. In the autumn of 1889, Oliver with his father and mother left London and took up their residence at Paignton, in Devonshire. This was partly on account of his parents' failing health, but it was also because his brother Charles was able to offer accommodation; for Charles, who had a music shop in Torquay, had lately opened a branch at Paignton. Oliver's mother died at Paignton on October 31, 1894. His father died there on November 16, 1896. From about 1897 to midsummer of 1909, Oliver dwelt in comparative solitude at a house known as Bradley View, in the neighbouring town of Newton Abbot, near Dartmoor. At Newton Abbot, he suffered tortures on account of molestation by boys of the locality. A more serious trouble was a bad attack of malarial jaundice. Miss Way, though herself old and frail, thereupon offered him quarters at the house, Homefield (Figure 7) in Torquay, which ultimately became his by purchase, and where he remained to the end of his life.

The portraits of him, reproduced in the Frontispiece, probably were taken in the year 1893. They are from old negatives long stored in a cardboard box bearing the inscription in his own hand:

"NEGATIVES of photographs of the present Dr. Heaviside—(taken by C. T. H.) at Palace Avenue, Paignton. Keep dry and the film sides in contact. The one with hands in pockets is perhaps the best, though his mother would have preferred a smile."

It must have been the portrait "with hands in pockets" that his friend Professor FitzGerald contrived to obtain from him in 1898, and concerning which FitzGerald wrote:

"I am sorry you did not give a less retiring view of your face. If you were one of those who had a great reputation for getting on by brazen pushiness, I could understand your fearing that your portrait being published might be misconstrued."

Heaviside scoffed at those who publish their photographs:

"It makes the public characters think they really are very important people, and that it is therefore a principal part of their biz. to stand upon doorsteps to be photographed."

Concerning a contemporary photograph of a group of members of the Institution of Electrical Engineers he remarked:

"Giants at the back. Pigmies at the front. I gave it, framed and glazed too, away to a Newton Abbot furniture dealer, for nothing, along with an old kitchen table."

In Figure 8, which is from a photograph of members of the Heaviside family, taken at Berrypomeroy Castle, Totnes, about the year 1893, Oliver is just to be seen in the far background, smoking his pipe. His father and mother are standing side by side near the centre of the picture; and next to his mother, on her other side, is Miss Way. Arthur West Heaviside is standing on the extreme right of the picture holding his hat in his left hand. Immediately in front of Oliver is Basil Bell Heaviside. Charles Heaviside is stooping down between his father and his brother Arthur. In front of Arthur is Colin, the third son of Arthur. Miss Ethel Heaviside is standing behind, between Oliver's father and mother.

Here, for a moment, it is well to consider his mode of working and his attitude of mind. Throughout his mathematical work in its final form, his writing was singularly neat, although it appears from marginal notes that he was often troubled to find a pen that suited him. An editor, hard to please in other respects, was constrained to confess: "No other contributor can approach the admirable clearness of your copy and the cleanness of your proofs." Mathematical solutions were not obtained by him on all occasions easily—they were frequently the result of strenuous labour and repeated trials. In proof of this, scattered amongst the drafts of his attempted solutions of problems, his perplexities at moments find expression in interjected remarks:

"This is fearfully complex. . . . Don't see how to simplify it at present, but I think it will work down to something simple in the long run. . . . Which is *right?* . . . Winna du! . . . No go! Save all this bother. . . . Notes on the Brays of the British Asses! Notes on the Brays! (British Association members.) . . . Hope. Hope. Hope. Swine. Swine. Swine. . . . All this is very fishy. . . . Revise it. . . . The subject is enshrouded in difficulties and ambiguities. . . . I cannot manage it to-night. . . . Quite fagged. . . . One success only leads to more failures. . . . Hinc illae lachrymae. . . . So it is dubious. . . . Patience. . . . Bah!"

For preliminary drafts of his mathematical writings he often used the backs of waste invoices from his brother's music shop—an investigation of a Fourier's series thus finds a few square inches on the reverse side of a stray account to somebody for a copy of "Love's Old Sweet Song," concerning which, alas, no trace of a corresponding term appears in any of Heaviside's equations.

In his extensive numerical work he would have saved himself much trouble if he had used a slide-rule, but he preferred to employ ordinary arithmetic, and occasionally a book of logarithms. He ciphered in bold figures, and so long as there was hope that a solution might be found, he was never thwarted by the labour of the calculations. He possessed a strong desire, amounting almost to a passion, that his work should be published as written. Ultimately, he nearly achieved his purpose. It was a requirement beset with difficulties, many of which were self-imposed. He wrote: "Experience has taught me that the refusal of a paper by any journal, for unconvincing conventional reasons, implies that the paper is unusually original and good. Fact!" There was, however, another side to this. In

1886 his wrath was kindled against an official who was suspected by him of having hindered the issue of a description of a system of telephony with which his brother had been associated. The charge was that this official "fell foul of it in a savage and even insulting manner and blocked the paper." To make matters worse, the technical press, at the zenith of his activities, was passing through an exasperating period of litigation. Even his staunch supporter, C. H. W. Biggs, then editor of *The Electrician*—who before the scientific world had learned to bow to the prerogative of Heaviside's genius, exhibited tolerance towards his obscurities and tact towards his idiosyncrasies, and who at last was thanked by him, "for the opportunity he gave me of exercising my philanthropic inclinations"—was constrained to admonish him:

Figure 2—Engraving of the Royal Mausoleum, Frogmore, Windsor, by Thomas Heaviside (Oliver's father).

"(May 30, 1887.) I would use your letter if I could, but it is dangerous in the present state of the law. . . . I may tell you that at present six of us have two libel suits each against us, or a round dozen altogether, and I venture to think that the cost even if we successfully defend ourselves will be considerable. . . . Candidly then I am afraid to use it, not personally, but . . . ."

"(June 1, 1887.) Do you not think it rather infra-dig in a scientist to be so moved at the doings of a scienticulist?"

Several years afterwards, Heaviside recorded that in 1887 he came for a time to a dead stop, exactly when making applications in detail of his theory "with novel conclusions of considerable practical significance, relating to long-distance telephony in opposition to the views at that time officially advocated." In that year also the editor of the *Philosophical Magazine* found that as no one, so far as he could discover, read Heaviside's articles, he could no longer afford space for them.

In 1888 another editor complained that the articles, so far as could be ascertained, were only read by a few professors, and "Professors, you see, do not advertise." Refined chastisement was also administered on October 31, 1891, from another quarter, when he received a letter as follows:

"I am desired to return you the thanks of the Royal Society for your Paper

On the Forces, Stresses, and Fluxes of Energy in the electromagnetic field

and to inform you that the Committee of Papers have directed it to be published in the *Philosophical Transactions*. . . .

P. T. O.
Both our referees, while reporting favourably upon what they could understand, complain of the exceeding stiffness of your paper. One says it is the most difficult he ever tried to read. Do you think you could do anything; viz., illustrations or further explanations to meet this? As it is, I should fear that no one would take advantage of your work.

Yours truly,
RAYLEIGH."

With reference to this he records in his note-book:

"It took six months before I heard that the paper was accepted for the Transactions. Then 3 months to get it set up in proper type. About 4 months (or 5) more before published. Great delays in correction. Printers humbugs."

Again, Heaviside resented the action of the Royal Society when the Secretary, on July 26, 1894, wrote to him:

> "I am desired to return you the thanks of the Royal Society for your Paper
>
> *On Operators in Physical Mathematics.*
> *Part III*
>
> and to inform you that the Committee of Papers, not thinking it expedient to publish it at present, have directed your Manuscript to be deposited in the Archives of the Society."

His annoyance in respect to delays of this kind lasted to the end of his life.

The same was true of his books. Volume 1 of *Electromagnetic Theory* took three years to put through; Volume 2 occupied a little more than four years. He calculated that if Volume 3 was to be first presented as serial articles, it would consume twelve years. So he gave up the idea of proceeding in that way.

It is necessary here to remember that Heaviside was not a mere equationist. He was a man of high purpose—a reformer. To establish his reforms he had to encounter conventions, and thus he was forced to think, to appear, and to act, as an individualist. In 1913 he wrote to a friend: "Pray don't ever call me a mathematician. I am a physical mathematician or mathematical physicist, and repudiate all mathematicians." This is the key to a great deal that is puzzling in his writings. In his time, a school had arisen that was intent upon finding physical significance in mathematical processes. With this movement, Heaviside was in whole-hearted agreement—but he went further, he made a direct attack upon extremists among pure mathematicians. He said:

> "Three pernicious results of looking for over much rigour may be mentioned. First, its enfeebling action on the mind . . . secondly, it leads to the omission from mathematical works of the most interesting parts of the subject because the authors cannot furnish rigorous proofs. Thirdly, it leads to mental inability to recognise the good that may be in other men's work should it fail to come up to their standard of rigour."

To account for his abstruseness, there is primarily the fact that his mathematics was of a higher order than could readily be grasped by his contemporaries. Like Newton's *Principia*, his works were for this reason destined in any case to be more admired than studied. He confessed that he was a voice crying in the wilderness—for vectors. His obscureness was further deepened because, following Maxwell, he strove to express his results in the most general form—not always as explicit cases that would have been more readily understood. To add to the difficulties, there was lack of continuity arising from transformation of serial articles and scattered memoirs, irregularly issued, into a treatise. His worst fault, however, was the omission of steps in the argument, especially when the breaks arose from needless digression to attack quaternions, scienticulists, 4π, or an "enemy."

He once expressed his motives thus to an editor:

> "(November 1, 1890.) Posterity. I don't think posterity will care to go to the British Museum to read up back volumes of the . . . . I write, or rather wrote, for the present generation. It was a stiff-necked generation. But I am assured by competent judges that I made some impression upon it in spite of its objection to be born again. . . . I never have, and do not intend to have anything to do with *contentious* discussions, as I understand 'contentious,' contending for the sake of contending, about nothing worth contending about. Legitimate scientific reasoning means that if anyone puts forward views which I consider wrong, and am interested in, and the matter is worth correcting, I have the right to do it, on scientific grounds."

With regard to learning, he said "sit down and work—all that books can do is to show the way." He insisted that we are, from first to last in contact with those quantities which are believed to have physical significance—instead of with mathematical functions of an essentially indeterminate nature—and also with the laws connecting them in their simplest form. His advice was to avoid "groping after mare's nests"—for example, in electrical theory, to shun potential—and to keep as close as possible to such variables as are known. He was proud of having been at one time a "practitioner" himself, and his correspondence shows that when practical men approached him in a way of which he approved, he was ever ready to assist them, as well as men of science, with their problems.

Repeatedly he was asked by editors to have mercy upon their readers, to write less "poetry" and more "prose," or to write an easy synopsis—but he was remorseless and relentless. His reply was:

> "Synopsis? Can't. The Lord will provide. He always does. I am aware and so is everybody that the practicians only glance at my articles, and that the readers thereof are a small minority. It always was so, save a few exceptional articles, and it always will be so. I am afraid you will think the above very unsatisfactory in relation to commerce. I can't help that, though I am very sorry. . . ."

Let us glance at the range of subjects at which this reformer worked. Physical science, when Heaviside entered it, had for two centuries been the battle-ground of contentions about the ether, vortex motion, light, electricity, magnetism, and gravity. During his boyhood and youth, Faraday, Thomson, Tait, Stokes, Rayleigh, Helmholtz, Weber, Gauss, and Maxwell had swept over the field. Moreover, an Atlantic cable had been made and laid, land telegraphs in a multiplicity of forms had been successfully developed, and practical details concerning the behaviour of dielectrics and transmission were thereby accumulated far beyond the range of what was then contemporary theory.

Advance in electrical communication systems in his time called chiefly for improvements in methods of measurement of the quantities to be dealt with in practical telegraphy and telephony, and for the interpretation of results in quantitative terms. To prepare himself for the tasks thus suggested, Heaviside faced the drudgery and self-sacrifice needed to render himself efficient; he grasped firmly the weapons of mathematics and practical experience, and he strode into action at the point where the work was most strenuous.

The article—his first—in the *English Mechanic* of July 5, 1872, is concise and convincing. Of like quality are his papers in the *Philosophical Magazine* of February, 1873, on the best arrangement of Wheatstone's bridge for measuring a given resistance with a given galvanometer and battery, and on duplex telegraphy. The years 1874 and 1876 are characterised by marked development; his papers on telegraphic signaling with condensers (*Phil. Mag.*, June, 1874), and on the "extra" current (*Phil. Mag.*, August, 1876), show that, equipped with the calculus, this youth of Camden Town had made Fourier's theorem his own, he had mastered what Sir William Thomson had revealed with regard to arrival-curves, and he had gone a long way towards interpreting Maxwell. Thus he was able to attack some of the new and then incomprehensible problems that accompanied the introduction of the Bell telephone. To the mystery of such questions he refers in his analytical paper—a treatise in itself—on electromagnets (*Jour. Soc. Tel. Eng.*, 1878), where he remarks that "this most sensational application of electricity appears to be very indifferent to resistance (sometimes), it being said to be sufficient merely to make earth 'through the boot and a blade of grass.'"

Telephonic currents were thenceforward to be his principal theme. If at this stage the telephone had not won his attention, he would probably have devoted himself to designing dynamos; for his paper, *Jour. Soc. Tel. Engs.*, June, 1881, on magneto-electric current generators was full of promise. His two great contributions, however, (1) On induction between parallel wires, and (2) On the theory of the propagation of current in wires, written respectively in 1881 and 1882, gave direction to his efforts, and firmly established him as a leader in rational telephonic and telegraphic engineering; for it was Heaviside who finally deposed guesswork, and who provided means that ultimately led to precision in telegraphic and telephonic transmission.

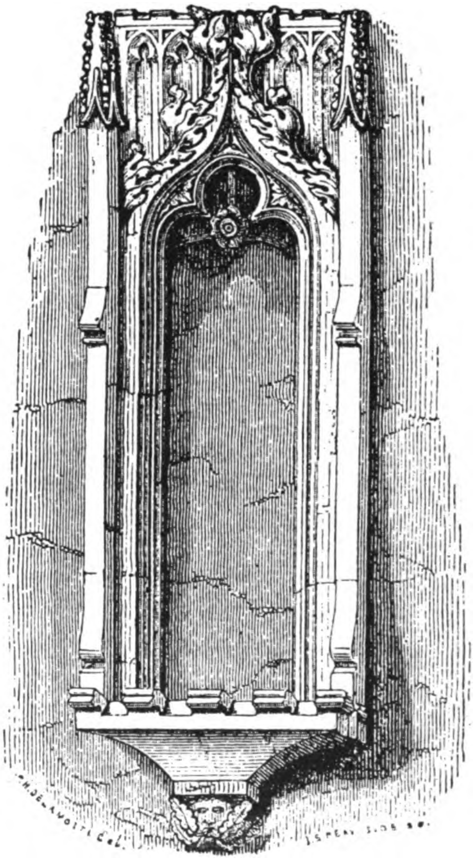
It was in the autumn of 1882 that he began his famous "Electrician" series of papers, about 500 pages, on electrical theory—vectors, potentials, units, energy, thermo-electricity, propagation of electrical disturbances through a medium, induction balances, models of viscous liquid—all mental equipment for the age of telephony and power transmission that was about to begin. This series led to contributions in 1885 that continued to the autumn of 1887, on electromagnetic induction and its propagation. To him, the ether was "the great store-house of energy." He studied the mechanics of a rotational ether in which magnetic force is allied with rotation. Maxwellian as he was, he complained that Maxwell had left gravitation out in the cold, and he directed attention to the fact that electrification is always found associated with matter.

Although, to gain the advantage of symmetry—and to be able to treat electromagnetic problems as elastic solid problems—he established, as nearly as he could, parallelism between electricity and magnetism, and he laid emphasis upon the absence of a magnetic conduction current. Thus magnetism to him, as to all the pioneers, was the transcending mystery of the universe. He introduced, in 1885, for those purposes of symmetry, the fictitious quality: "magnetic conductivity." To describe the general parallelism, he adopted, not quite happily, the word "duplex," and in this sense he exhibited the electric, magnetic, and electromagnetic equations in "duplex" form; i.e., symmetrical with respect to electric and magnetic notions. The immediate objects of his attention then became the corresponding *fluxes* and their variations. Potentials he relegated to a secondary place. So far as they concerned the state of the medium, potentials were in fact treated by him as auxiliary quantities, devoid of physical significance.

The experiments of Hughes, in January, 1886, confirmed Heaviside's theories of surface conduction along wires. In the spring of that same year, Heinrich Hertz definitely established by experiment the wave character of electromagnetic transmission through space and through wires. The experiments and writings of Hertz produced upon Heaviside a profound and stimulating effect.

The introduction to Heaviside's papers on self-induction in wires, beginning with his article in the *Philosophical Magazine*, 1886–1887, indicates that he was led from his early experiments on Wheatstone's bridge to his investigation of the induction and resistance of long solenoids containing cores, and thence to the mathematical study of the transmission of current "into" wires by diffusion from the external dielectric. With these papers may be grouped his remarkable article, written in 1887, but not published until 1892, on telegraph circuits, and his communications to the *Philosophical Magazine* of December, 1887, on resistance and conductance operators, the whole comprising, in about 200 pages, the foundation of modern theory of telephonic and telegraphic transmission, united with dynamics in the conception of forces and stresses. In effect, Heaviside's Expansion Theorem enables an *explicit expression* for the currents as functions of the time to be derived, for any network, from the *differential equations*, by means of intermediate *operational equations*, under the conditions (i) That the currents are initially zero, and (ii) That given potential differences are applied at various given points of the network. Or conversely, his theorem enables the potential differences to be derived from the currents. His method consists in prescribing rules for obtaining the operational equations, and rules for translating the solution of the operational equations into solutions of the original differential equations.

Another group of investigations, almost inseparable from the preceding, had its origin in his article in the *Philosophical Magazine* for February, 1888, on electromagnetic waves, especially in relation to the vorticity of the im-



Kidlington, Oxfordshire, c.1450.

Figure 3—Example of Engraving Work by Oliver's Uncle, John Smith Heaviside.

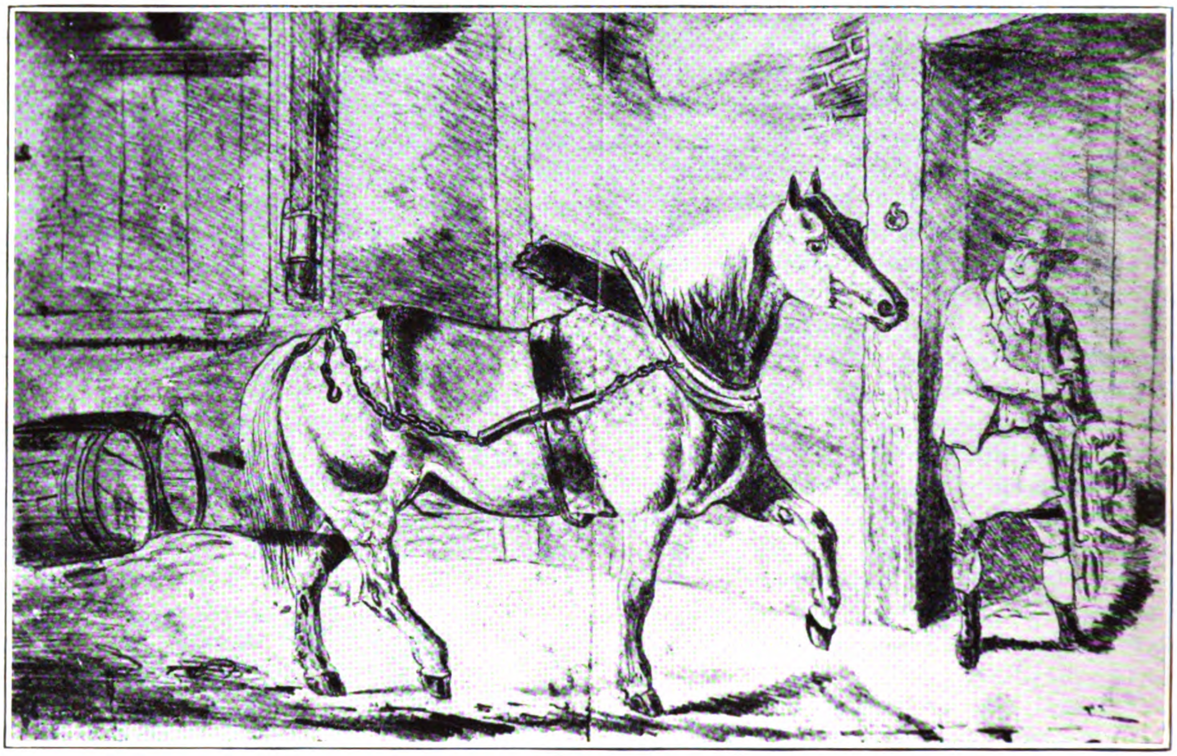


Figure 4—Drawing Inscribed "The Cart Horse. By Oliver Heaviside. Aged 11."

pressed forces, and on the vibrations of electromagnetic systems. By "vorticity" he meant the "curl," familiar enough at that time to a few Cambridge, London, Dublin and Scottish mathematicians, but to the rank and file of his contemporaries, a sore perplexity. Lastly came his treatment of electromagnetic radiation, and the Heaviside Layer, concerning which it may be helpful to observe that in Volume III, Chapter X, of *Electromagnetic Theory*, 1922 edition, p. 331, his article bears the superscription: "Theory of Electric Telegraphy. Encyclopaedia Britannica. Tenth Edition. Reprinted by permission of the proprietors of The Times. Written June 1902." This forms part of his treatment of "Waves in the Ether." He begins with the case of radiation between two coaxial conical conductors with a common apex. The radiation is supposed to go from the inner to the outer cone symmetrically in spherical sheets, with the apex as centre. By assigning various values to the semi-vertical angle of the cone or cones, he derived several cases, some corresponding to "wireless" transmission—a flat plane and a vertical wire projecting from it at the apex, spherical waves from the apex, waves from a Hertzian vibrator, two parallel wires, waves along wires containing sharp bends, and "wireless" waves across sea-water. He explained that the waves accommodate themselves to the surface of the sea in the same way that waves follow wires. Then comes the important statement:

> "The irregularities make confusion, no doubt, but the main waves are pulled round by the curvature of the earth, and do not jump off. There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other."

There is reason to suppose that this article was published towards the end of the year 1902, and that it was the last the editor of the *Encyclopaedia Britannica* (Tenth Edition) received before publication of the volume in which it is contained. Priority for the layer is not discussed by Heaviside. Regarding priority, therefore, the wise will follow the advice of Newton touching the origin of the theory of light: "To avoid dispute, let every man here take his fancy."

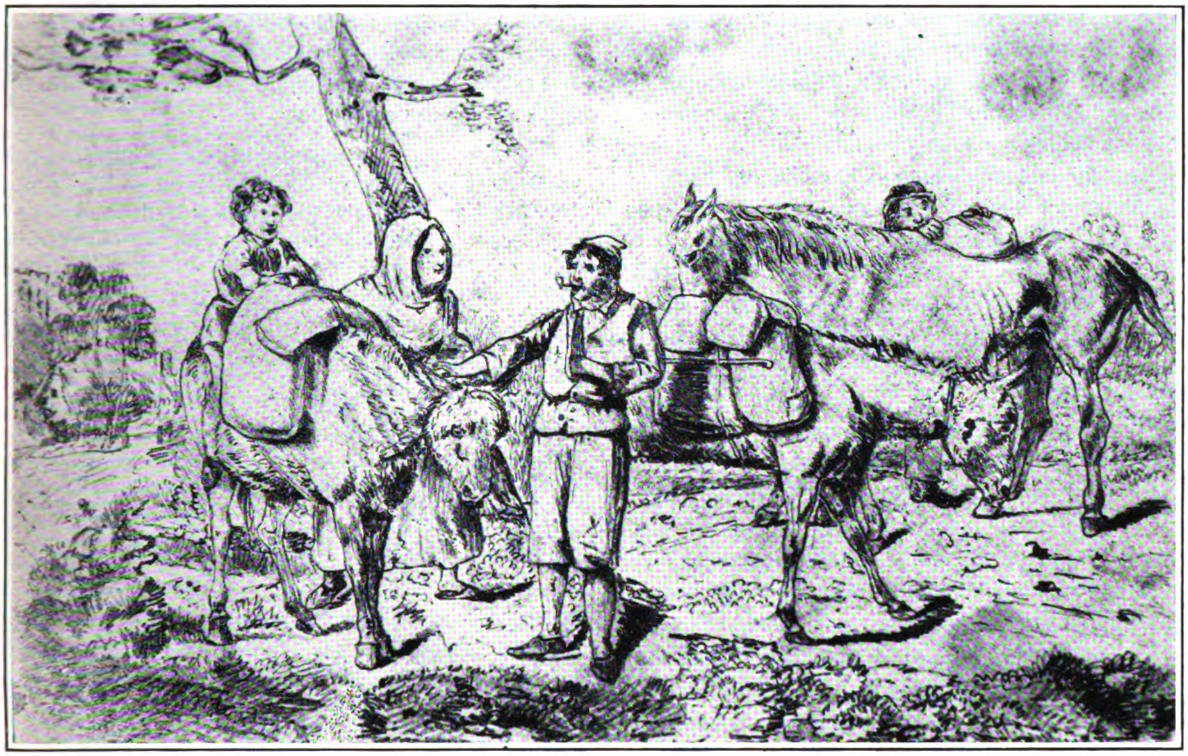


Figure 5—Drawing Inscribed by Oliver Heaviside "2nd Work by Oliver Heaviside (No others preserved)."

Amongst Heaviside's loose manuscripts is a draft in which he has recorded that in 1902 the cable companies were already considering what the effect of wireless telegraphy might be upon their enterprises. He entertained doubt whether it would have serious influence upon them unless a quick method of automatic wireless signaling were adopted. He was at that time prepared to be consulted as a scientific man, and as an old "telegrapher," but "he was not disposed to do sums set by unscientific practicians who despised mathematics." He saw that what was needed was experiment. To his mind, the scientific work had been done. He had shown the way to improve cable telegraphy—beyond what was possible by more copper and less capacity—"first by the principle of increase of inductance, and next by the invention of a practical substitute for uniform inductance—coils at intervals, one per mile for instance." The memorandum points out that the cable companies were free to explore the matter, for he says: "I did not protect it. There can be no patent for it in England except for improvements thereon. . . . Now the wireless telegraphy frightens them. Well, I wish they may have good reason to be frightened."

Concerning the prospects for wireless telephony, he expressed himself, on April 3, 1914, as follows:

> "The atmospheric disturbances will be very troublesome perhaps. Still the idea of talking from pole to pole is rather attractive, or to hear yourself talk 24,000 miles."

The sequestration in which he existed robs the biographer of the ordinary means of approach to knowledge of him. Yet his seclusion, like that of Barrie, was comparatively well known. Fortunately, the opportunity occurs to disclose for the first time some of his correspondence. The introduction of extracts from this source will disturb continuity, but there is compensation for a broken story in a new impression.

It is first necessary to piece together some scattered facts relating to electromagnetic wave history. The experiments of Bezold (*Berichte der Bayrischen Akad. d. Wissensch.*) on electric waves along wires were described in 1870. They were then unknown to Heinrich Hertz, and they were unknown to FitzGerald (born August 3, 1851; died February 22, 1901). On November 17, 1879, FitzGerald (Figure 9) read a paper before the Royal Dublin Society on the possibility of originating wave disturbances in the ether by means of electric forces. He there directed attention to Maxwell's statement of the hypothetical conditions under which an electrical disturbance might be propagated in free space. FitzGerald at that time (1879), taking a case of insufficient generality, arrived at the wrong conclusion that Maxwell's displacement currents, however produced, will "never be so distributed as to originate wave disturbances propagated through space outside the system." In May, 1882, however, after referring to a more general solution of Maxwell's equations, given by Lord Rayleigh, he withdrew his earlier expression of opinion, and he admitted that "a simply periodic current would originate wave disturbances such as light." He added that it might "be possible to obtain sufficiently rapidly alternating currents by discharging condensers through circuits of small resistance." The crucial experiment of Hertz was in 1886.

It was FitzGerald who reviewed, in 1893, Heaviside's Electrical Papers, and who acknowledged their value

> ". . . because they teach a sound theory of telegraphs and telephones, and of other matters . . . which, there is every prospect, may lead to vast improvements in telegraphy and may even make it possible to work a telephone across the Atlantic."

Regretfully this learned and sympathetic reviewer complained that Heaviside jumped deep double fences and introduced short-cut expressions that were woeful stumbling blocks to the slow-paced average man; he criticised also the frequent repetitions, and he never forgave him for abandoning quaternions. Nevertheless he ascribed to Heaviside the credit for having cleared away the débris of the battle fought by Maxwell. Heaviside, he observed, had reduced the maze of symbols—electric and magnetic potential, vector potential, electric force, current, displacement, magnetic force, and induction—practically to two, electric and magnetic force. He had established symmetry throughout the whole of electromagnetics. He had extended the theory of wave-propagation in complicated media; and he was responsible for the most important application of electromagnetic theory to telegraphy and telephony. Then comes the highest tribute of all:

> "Since Oliver Heaviside has written, the whole subject of electromagnetism has been remodeled by his work. No future introduction to the subject will be at all final that does not attack the problem from at least a somewhat similar standpoint to the one he puts forward."

The world in 1886 awoke from its lethargy and became conscious of the existence of electromagnetic waves. Men to-day who remember the delight with which the convincing experiments were at last seen, discussed, and repeated, will recall the pleasure of discovery that in 1886 pulsed through the world. It was a victory in which all rejoiced. By doing full justice to Bezold, Hertz won more than fame. His attitude, equally correct, towards Heaviside can now be traced; for amongst correspondence just made available are letters that tell their own story. The first, from Hertz at Karlsruhe to Heaviside in Devonshire, is dated March 21, 1889:

> "I more clearly understood your methods from your letter than from your book, where they lie hidden beneath a great number of special cases. I am quite of your opinion, that you have gone further on than Maxwell, and that if he lived he would have acknowledged the superiority of your methods. A great point is, I think, that you do away with unnecessary potentials. Electrostatical (scalar) potential and magnetical (scalar) potential ought to remain I think, but in statical phenomena only; in dynamical problems no potential ought to occur, and no vector potential ought to occur at all. I had also reflected on these things. . . . I find it so very difficult to follow your symbols and your very original mode of expressing yourself. You know mathematical symbols are like a language and your writing is like a very remote dialect of it. . . . Your methods are more than your symbols. . . . I was very interested to hear you had come so near to see yourself electromagnetic waves, and was glad for my sake you did not follow up the indication you had. I cannot quite agree with what you write about the propagation of spirals. I cannot but think that from a good theory quite a distinct velocity ought to come out, and very simply.
>
> If Maxwell lived, I think he would have more joy in my experiments and would have more reason to be proud in their result, than I can have."

The reply is unknown, but on May 5, 1889, Hertz continued:

"The fact is that the more things became clearer to myself and the more I then returned to your book, the more I saw that essentially you had already made much earlier the progress I thought to make, and the more the respect for your work was growing in me. But I could not take it immediately from your book, and others told me they could hardly understand your writing at all, so I felt obliged to give you warning that you are a little obscure for ordinary men."

Again, on August 10, 1889, now from Bonn, Hertz wrote:

"Theory goes much further than the experiments, for the experiments hardly come to tell in a whispering voice what theory tells in clear and loud sentences. But I think in due time there will come from experiment many new things which are not now in theory, and I have even now complaint against theory, which I think cannot be overcome until further experimental help. You speak of calculating the frequency of such oscillating systems as I make use of. I often tried to get the oscillating time exactly after Maxwell's theory but did not get any. I then considered a simple sphere perfectly conducting in a perfect dielectric. There were no more difficulties in the analysis, but yet I got no more oscillating time. I think there is none. Did you ever work out the problem completely? To my great grief, I have no time to go further on in these things for a year or so, having to spend too much time with my lectures, laboratory, examinations, etc."

To this, Heaviside probably responded promptly, for on September 3, 1889, from Bonn, Hertz explained:

" . . . As to the oscillation or oscillations of a sphere, I attacked the problem just in the way you propose but got no result. I think the damping is so great that disturbances go away almost aperiodically. This ought to be otherwise in very elongated ellipsoids, but in these the analysis becomes very difficult. . . . You may believe that I was fully in earnest when I said you could not learn very much of my experiments. I meant to say, that he who was fully convinced of the truth of Maxwell's equations and was able to interpret them, did know as much about these things before my experiments as after them. I did not mean to say by this that the experiments were of little worth, for there were many people not convinced of those equations or not able at all to see what they meant. And then I hope for many new things to come from the experiments. . . . The motion of the ether relatively to matter—this indeed is a great mystery. I thought about it often but did not get an inch in advance. I hope for experimental help: all that has been done till now has given negative results. . . . Take a copper sphere rotating in a homogeneous magnetic field. You cannot treat the case without having recourse to action at a distance. Maxwell's solution is by action at a distance. And I do not see how it could be otherwise before we know if the ether turns round with the sphere or is at rest, or where is the frontier between the moving and the resting ether. . . .

As to the structure of the ether, . . . the structure of all the models imagined until now is certainly not the structure of the ether; in these points I am absolutely of your opinion."

In this letter Hertz enumerated the particulars in which, in his judgment, Maxwell's theory required to be amended:

" . . . for example the strains imagined by Maxwell to account for the motions of ponderable matter—these strains would tend to give motion to the interior of the ether itself, except in the very special case of statical problems. Now if no such thing occurs (which I think probable) the system is false; or if such a thing occurs, the system is incomplete."

Though Hertz and Heaviside never spoke face to face, their friendship deepened sufficiently to enable Hertz to write from Bonn on December 31, 1890:

"Dear Heaviside,

I send you my very best wishes for a happy New Year. . . . If you would only take a good form, a book of yours on the theory of electricity would have a great success in England and abroad. But I fear you have some pride in this, not to yield to the understanding of others. I think this is a false pride, you certainly are not aware how very difficult your papers are to understand to others, and it is old wisdom that the many will expect you to come to them and not come up to you, be your merits ever so great."

Thus it was not for lack of good advice that Oliver continued to indulge in the luxury of his own obscurity. Towards Hertz, he had the kindliest feeling. He concluded that, so far as the ether, as distinct from matter, was concerned, the Karlsruhe experiments fully confirmed Maxwell's theory. Matter would require further consideration. Maxwell's application of electromagnetics to explain phenomena associated with waves of light and heat in solids and liquids he knew to be imperfect, but the best available.

There is strange irony in the fact that Heaviside's secluded home in Devonshire, half buried amongst its brambles, its doors closed to all save the rarest visitors, its interior too often comfortless, should at the same time have been to a large section of the most advanced men of science a temple of wisdom, the place of the oracle, the court of ultimate appeal. The proof of this is in his correspondence. Physicists at Oxford who wrote to him referred occasionally to his hermitage as "The Inexhaustible Cavity," and there is a story that a letter addressed to him at "Inexh. Cavy. Torquay" was duly delivered. The reference, no doubt, was to the cave of Adullam (I. Samuel, XXVII, v. 2) into which everyone gathered that was in distress. Sometimes the perplexing problems sent to him were relieved by lighter matter, such as the following from C. V. Burton:

> "Crookes (P.R.S.) was dined at Jesus Coll. Oxford a little time ago. All sorts of 'nutts' came to meet him, but he spoke hardly a word to anyone. According to one account, he has found that if he talks too much after dinner he makes no new discoveries the next day."

There was a desire to prevail upon Heaviside to clear up the distinction between his vectors and quaternions, and to establish harmony if not coincidence. He held, however, that—

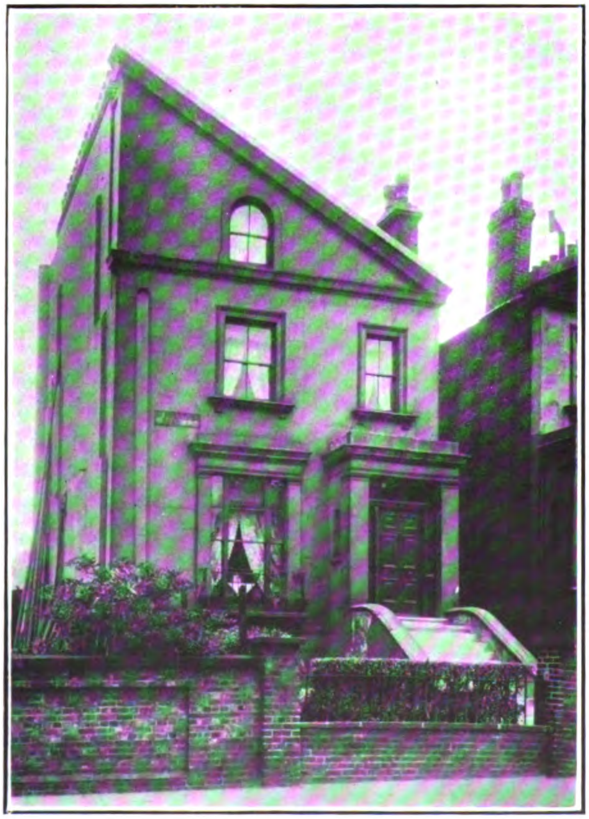


Figure 6—The House, 3 Saint Augustine's Road, Camden Town, where Oliver Heaviside resided from 1876 to 1889.

> "As vectors are not quaternions, the algebras cannot be naturally the same. Quaternions should come into vector algebra as quaternions—not as vectors. . . . Quaternions belong to trigonometry, which is the science of ratios between differently directed vectors. . . . Vector calculus belongs to physics."

The playground remained covered—as ever, since Descartes—with broken models of the ether. One of the first to acknowledge the wisdom that emanated from the inexhaustible cavity was Sir Joseph Larmor, who confessed in a letter dated October 12, 1893:

> "I am practically a convert to vector analysis and I mean to learn up the machinery immediately I have time."

Later he added:

> "My present view is that atoms are vortices in the medium, then magnetism is their vorticity, and a magnetic field tends to align them."

On February 12, 1898, he sent Heaviside "to look at" a copy of his paper on rotational ether, making the electric field of an electron both polar and circuital at the same time, in a way "that carried some evidence of naturalness." It had cost him three years to prepare, and yet he declared, "I am not so sanguine as to hope that more than say two people will read it." A few weeks later, Heaviside was able to send him Volume II of *Electromagnetic Theory*. For this Larmor, on May 8, 1899, thanked him, observing that it contains

> " . . . much wholesome castigation of my own profession, which is misled sometimes by the power of symbols into the belief that such a thing as rigorous exactitude can reign in any created product of the human mind. I see you still decline to countenance a rotational singularity or electron. . . . I believe I see signs that some previous oft heard opponents of all such notions now exhibit a tendency towards taking them for evident. But that is the way of the world, as you I presume are aware."

Sir Joseph Larmor was probably referring here to Lord Kelvin.

In 1898, Heaviside was consulted by John Milne with regard to seismographs and the interpretation of seismographical curves. Milne was prospecting and negotiating for a volcanic site near to Heaviside, on which to establish an observatory; for according to Milne—

> "If the National Laboratory is to be at Kew, so far as certain kinds of work are concerned it might equally well be on a sponge."

But the site Milne had prospected and coveted turned out to be not volcanic after all.

The gathering strength of the influence of Oliver Heaviside upon his contemporaries is everywhere apparent in the correspondence. Amongst the letters, for example, is one from David Hughes, dated May 19, 1899:

> "I should like to ask you if I am wrong in supposing that theory leads to the conclusion, 1st that self-nduction is beneficial to long-distance telephony, and 2nd that you would recommend for that purpose *Iron wires in place of Copper.* I mean wires of the same resistance."

There is another from David Hughes, dated June 6, 1889:

> "Remember that I fully agree with Hertz's experiments and think Maxwell's electromagnetic theory of light probably—but the only point in doubt in my mind is the permeation of a current from the inside to the outside. . . . If you can cite any experiment or any reasoning that would guide me in finding a method by which it could be demonstrated, your reply would be valuable to scientific truth."

Complete triumph came on January 10, 1889. The date is noteworthy because it is that upon which The Society of Telegraphic Engineers and Electricians altered its name to The Institution of Electrical Engineers. After the transfer formalities, Sir William Thomson (Lord Kelvin) took the Chair and gave an address on "Ether, Electricity and Ponderable Matter." He dwelt upon the history of electromagnetic induction in cable transmission, and he agreed that in his early theory he had not taken it into account at all:

> "But in the meantime it has been worked out in a very complete manner by Mr. Oliver Heaviside; and Mr. Heaviside has pointed out and accentuated this result of his mathematical theory—that electromagnetic induction is a positive benefit: it helps to carry the current. It is the same kind of benefit that mass is to a body shoved along against a viscous resistance."

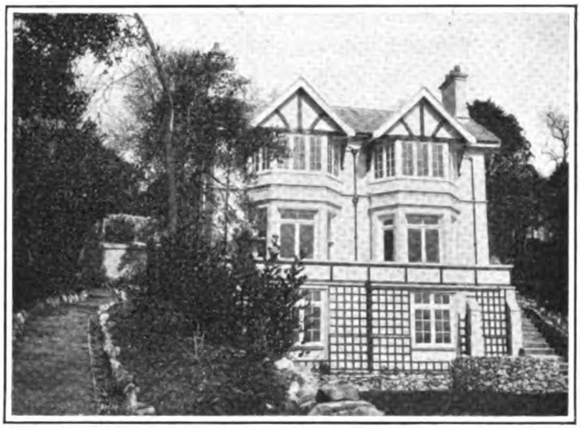


Figure 7—Homefield, Torquay, Now Known as Highwold.

The question of the choice of metal for conductors where "impulsive current" is concerned was discussed at a meeting of the Institution of Electrical Engineers on May 9, 1889, when Dr. J. Hopkinson was in the Chair. It was on this occasion (*Jour. Inst. Elec. Engrs.*, Vol. XVIII, p. 497) that Professor D. E. Hughes declared that "he could not agree with the theory of Oliver Heaviside if it leads to the conclusion that iron for telephone wires is better than copper." Dr. Hopkinson intervened and pointed out that Heaviside was very guarded in the statement, and had said "that an arrangement of iron was suggested which might be an improvement, but the ordinary iron wire was recognised as being very inferior in practical conductivity to copper wire. . . ."

On June 26, 1893, an editor wrote that John Perry had been for a long time wrestling with the subject of telephoning through cables, and "felt" that Heaviside's conclusions were right but could not follow the working. It was remarks of this kind that elicited from the "cave" the observation that the new theory "is so obscure that it has attracted a good deal of attention." Perry realised that if Heaviside would write a book that could be easily understood "it might pay," and he thought that he himself would be a good "foolometer." From a letter of FitzGerald (February 2, 1894) it appears that Perry would have been glad to collaborate with Heaviside in this venture. The precise opinion Perry held at about this time is recorded in a letter (August 4, 1893) to a mutual friend:

> "Now I rank Heaviside with those two men (Kelvin and FitzGerald) but I never pretend to be

able to read Heaviside. I wish I could, and so do a lot of people like me. . . . Somebody will have to write down Heaviside to our level."

With refreshing candour, ever associated with John Perry by those who knew him, he wrote to Heaviside (March 4, 1896) his confession:

"I only dip into your work to take out what is useful to myself. I only know you to be the great man you are through him (FitzGerald)."

An important part of the task of freeing the works of Heaviside from their obscurity, of enhancing their value by numerical examples, and of inspiring them with new life directed towards practical achievement, was reserved for Henry Malcolm, who in 1912 began and in 1917 completed his classic treatise, "The Theory of the Submarine Telegraph and Telephone Cable."

The correspondence of Heaviside reveals his esteem for FitzGerald, who, as he expressed it, "belonged to the class of first-rate scientific men of the profounder sort who, not having any pretensions, only become known to their contemporaries." Concerning scientific men of the contrary type he observed: "There is no need to go without fame if you really want it." It is appropriate therefore to take the opportunity that now for the first time presents itself, of making known some of the opinions and criticisms that passed between these two remarkable philosophers. FitzGerald, at Trinity College, Dublin, began by tilting at Heaviside's innovations. He wrote to him:

"(September 26, 1892.) I hope you will succeed in making the ordinary mathematical physicist think in vectors, though I do not think your notation an improvement. You see, I was 'riz' on Tait and get very much muddled by your omission of S; and when one gets bothered every turn one naturally takes a dislike to the botheration. . . ."

"(January 4, 1894.) Trouton took up the telephone question rather by the way and has gone off on what he was at before, when he found it so complicated and unintelligible."

"(March 15, 1895.) You say Maxwell's (magnetic theory) is all a muddle. So it is: but there is an underlying stratum of explicability, I think, which must have been unconsciously guiding him."

"(June 21, 1893.) Maxwell's electro kinetic moment, A, was a crude way of imagining that the *current* had all the inertia, which is quite out of date now thanks to you—but it was very well when he wrote. . . . I cannot say that I am quite satisfied with your suggestion that in an imperfect conductor there are local electric currents with accompanying magnetic inertia as a way of getting over the statement that all the inertia is magnetic. It does not diminish the necessity for taking account of some inertia besides that appearing in the form of magnetic inertia round the current, because *wherever* a current exists some local energy is degraded *in situ* and if this has accompanying inertia without an external field we ought to add on to all our currents a term to express this. Just as the magnetic field due to two parallel wires cannot be completely supposed due to one wire between them carrying the sum of their currents, so, if we have to take account of internal fields between the molecules, we should proceed to do so, and *one* way of *representing* it would be in the *form* of inertia of current.

As regards the question of electric energy being potential, and magnetic kinetic, that is not in question here. When a spring is bent its energy is potential and still there is kinetic energy involved *during the time of its being bent.* What seems to me most likely is that during the time that displacement is taking place there are two sets of things going on. There is a magnetic force and accompanying induction (flow) taking place all round the displacement current which is proportional to the rate of change of the displacement and is the seat of *almost* all the kinetic energy. But besides this there is the change in structure of the medium going on which we call electric displacement and which is *increasing* as long as the rate of change continues constant; i.e., there is something increasing while the magnetic flow is constant. This is proved by the fact that there is electric force developed tending to push back the electric displacement. Now this something that is increasing must be some other motion than the magnetic flow, for magnetic flow cannot exist without calling up any reaction of the kind considered, and it seems to me as if this something increasing must have some inertia, for *no* change can take place without *some* inertia somewhere, and if this change *is* different from the magnetic flow then there *is* some inertia, maybe very little, in addition to the magnetic flow.

I think, however, there is a possible suggestion that what free ether resists is curl of magnetic flow, and then of course, the inertia of the flow would not differ from that of its curl—this latter being only a particular distribution of flow. But even then the *curl* is not increasing, it is constant, so that even though it is resisted, how can the resistance increase with the time? That is, I fear, special pleading, because the flow itself being a changing thing, its curl is so too. However, then comes the difficulty about what is happening between two spheres while the electric displacement is changing. There is no magnetic flow, therefore no curl, and so the curl of magnetic flow cannot be the something that is elastically resisted, unless of course you consider how the displacement *begins;* and in a non-conductor there must be the current to the inside of the sphere *somewhere* and there is accompanying curl somewhere; and from this point of view it is interesting to see *how* the electric energy grows at the various points within the sphere as they are gradually deserted by the magnetic force leaving its integral curl behind. Is that possible? I am afraid thinking these things out on a sheet of paper thus leaves them very muddly.

As to electric energy being essentially kinetic as well as magnetic energy, I have no doubt, but agree with you in thinking that provisionally it helps matters to consider one of them as kinetic and the other as potential. I return to my difficulty. Even in the case of curl being resisted, curl to be resisted must mean some changed structure other than uncurled flow, and this changed structure will have some accompanying inertia. Final thought: But perhaps different from the curly inertia.

I am afraid I am very hazy myself and am working more or less on my own model ether for concrete ideas, so that I am afraid I cannot make it very clear to another."

"(June 21, 1893.) When a current is started near a permanent magnet, the energy spent in producing it is quite independent of the presence of the magnet: Whence then in this case comes the energy of the field? I can only suggest that the permanent magnet is like a coil of a practically infinite self-induction, and that the energy of the field comes from it as it would from a neighbouring coil of perfect conductivity."

"(August 22, 1893.) Thank you very much for your letter. It clears up what I was quite hazy about. I had forgotten the momentum given to the ether, though I had been rather harping upon it lately in the case of the radiation of waves. . . . There is merely radiation of energy from two electrified bodies rotating round one another. There merely is a system of corkscrew waves being constantly generated . . . any regular periodic disturbance confined within a finite space must be continually creating new waves. . . . The action between two vortex rings in a perfect liquid is not . . . *propagated* from one to the other. It is due to the fact that each vortex ring is accompanied by motion everywhere, i.e., each vortex ring is itself really infinite and each ring involves all the others. Effects due to this kind of action not being propagated are simultaneous everywhere, and—as some actions of this kind must, I think, exist—it seems to me extremely probable that gravity is *the* action of this kind we are looking for. In that case there would be no question of its rate of propagation, it would be due to the fact that each atom of matter is infinite, *the* most probable hypothesis possible.

Yours sincerely,

GEO. FRS. FITZGERALD."

In March 1896, FitzGerald wrote to express his satisfaction that Heaviside had accepted the Civil Pension awarded in recognition of services to his country. He attributed the negotiation of the matter chiefly to John Perry and to Lord Rayleigh. An announcement that probably caused far more merriment in the "Inexhaustible Cave," however, was made by FitzGerald on June 8, 1896:

"I had a long correspondence with (Lord Kelvin) and his last letter says that he gives up everything he ever wrote about the ether. I hope he is not still quite so down in the mouth about it."

This was followed, on May 7, 1898, by a note to the effect that:

"Lord Kelvin, with his usual impetuosity has rushed at a single fluid theory of electricity—but he is very rash."

Formal correspondence was followed by a visit, of a few hours, of FitzGerald to Heaviside at Torquay and of cycle rides with him. They were men of such presence that those English lanes must have thought King Arthur and one of his Knights passed again to Camelot. The scene too quickly changed to Dublin, whence FitzGerald wrote:

"(May 7, 1899.) Have you worked at the propagation of waves round a sphere? A case of this is troubling speculators as to the possibility of telegraphing by electromagnetic free waves to America. It is evidently a question of diffraction and I think must be soluble. Perhaps the case of propagation round a cylinder would be easier. . . ."

"(September 21, 1899.) I am delighted to hear that you have set up that Aeolian. You are so fond of music I am sure it is very good for you and will help you to do more and better work than you could ever have done without it. . . ."

By this time the authoritative character of utterances from the oracle was recognised even by so distinguished a literary purist as Dr. Murray of Oxford, who, on March 17, 1899, appealed for the derivation of "Impedance." In reply, the lexicographer was referred to:

"The Electrician, July 23, 1886, p. 212; Electrical Papers, Vol. 2, p. 64, and to the quotation—'Let us call the ratio of the impressed force to the current in a line when electrostatic induction is ignorable, the Impedance of the line.' . . ."

Amongst the few contemporaries capable of appreciating to the full the merits of Oliver Heaviside was George Minchin who, from Trinity College, Dublin, had been appointed Professor of applied mathematics at the Royal Indian Engineering College, Coopers Hill, near Windsor. Mathematician, physicist, poet, and lawn-tennis player, he excelled in all that he set his mind and hand to do. He was a pioneer in photo-electricity and an early enthusiast in wireless telegraphy, especially in the use of an antenna; his skill in expressing in clear terms mathematical conceptions was unexcelled, and his joyous outlook made his friendship one of the best possessions. FitzGerald visited him at Coopers Hill College and wrote from there to Heaviside. This, so far as can be traced, was the last of their communications; for FitzGerald died but a few months later—died as did Maxwell and Hertz, before reaching fifty years of age.

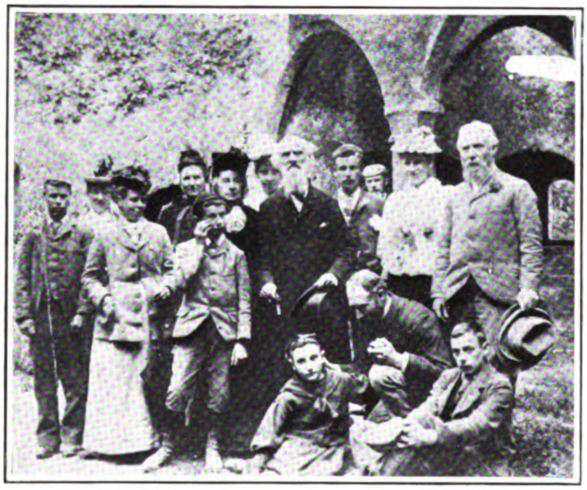


Figure 8—Group of the Heaviside Family.

"(July 12, 1900.) I was fortunate in being with Larmor in Cambridge when your letter was forwarded to me, and so I asked him about the difference between himself and your work, and he pointed out at once what would have taken me some thought to discover. It all arises from the difference he takes between a *moving electron* and a changing displacement. The electron is certainly a change of place of the point, but we cannot say that the changing displacement is a real motion in the direction of the displacement. The electric displacement at a point is, no doubt, represented by a vector, but it is very unlikely that it is really a simple displacement of the point: it is much more likely to be a rather complex change in the structure of the ether at the point, which can be *represented* by a vector. In consequence of this difference, Larmor separates the electric force, which acts on the ether and produces the electric displacement, from the force on a moving electron due to its motion across a magnetic field. When matter moves across the ether in which there is magnetic force, this latter is what produces the electric current, i.e., a current of electrons. Its value is

$$V\dot{\rho}H$$

(V in FitzGerald's notation here represents vector product) while there is no electric force producing any displacement of the ether due to the motion: unless the induction changes owing to the moving matter and so produces an electric force that acts on the ether.

Larmor, working with his abominable potentials separates them as

$$\epsilon_1 = -\frac{dF}{dt} - \frac{d\phi}{d\eta}$$
$$\epsilon_2 = \dot{y}c - \dot{z}b$$

and the ether being considered as standing still ($\dot{x}, \dot{y}, \dot{z}$) can only refer to moving electrons. The two together produce the *displacement* which, when changing, is partly changing ether displacement and partly current of electrons, and are accompanied by the magnetic force,

$$\dot{D} = V\Delta H.$$

I think there is very great difficulty in deciding what is the best assumption to make as to the interaction of ether and matter when they are considered, as you consider them, as *continuous* interpenetrating media. Larmor, by assuming a definite hypothesis as to the nature of matter and its connection with ether by means of electrons, (is enabled) to decide which of different suppositions is best.

I have to go off now to help Minchin to put up some wireless telegraph poles. I was very sorry indeed to hear of your (bicycle) accident with the hen. Hope you are getting over it all right and that it won't make you afraid to continue to cycle.

Yours sincerely,
GEO. FRANCIS FITZGERALD."

In the introduction to the Collected Scientific Writings of FitzGerald, there is a letter from Heaviside—the real Heaviside, at his best—disclosing very tender feeling, written at the time of FitzGerald's death:

"I only saw him twice knowingly, once for two hours, and then again for six hours, after a long interval; yet we had a good deal of correspondence at one time, and I seemed to have quite an affection for him. A mutual understanding had something to do with that. You know that, in the pre-Hertzian days, he had done a good deal of work, not large in bulk but very choice and original, in relation to the possibilities of Maxwell's theory, then considerably undeveloped and little understood; and his way of looking at things was more like my own than anybody's. Well, he found that I had done a lot of work in the same line, and he was most generous in recognising and emphasising it. Too generous, of course . . . he used to write to me a good deal about electromagnetic problems, and I laid down the law to him like—like myself, in fact. He took it all very pleasantly. But I knew all the time that he had a wider field than myself, and no time to specialise much."

Between the years 1855 and 1912, during which the theory of electrical transmission through telegraph and telephone cables was built up, the three electricians chiefly responsible for advance in that theory were Maxwell, Kelvin and Heaviside. Heaviside's appreciation of Maxwell is manifest. Although his acknowledgment of Kelvin's early work is definite, it was not until the year 1889—when Kelvin acclaimed Heaviside—that their acquaintance with one another began to glow. There are two letters from Kelvin to him that serve to illustrate this:

"(Glasgow University. November 4, 1888.) Dr. Francis forwarded to me at Cambridge your letter with accompanying papers. I sent him back immediately the papers for publication in the *Phil. Mag.* but I don't agree that velocity of propagation of electric potential is a merely metaphysical question. Consider an electrified globe, A, moved to and fro, with simple harmonic motion if you please, to fix the ideas. Consider very quickly acting electroscopes B, B', at different distances from A. If the indications of B, B' were in exactly the same phase however their places are changed, the velocity of propagation of electric potential would be infinite; but if they show differences of phase they would demonstrate a velocity of propagation of electric potential. Neither is velocity of propagation of 'vector potential' metaphysical. It is simply the velocity of propagation of electromagnetic force—of 'electromagnetic waves' in fact."

"(Glasgow University. April 27, 1899.) I am not bigoted to either 'spin' or 'rot' or 'turn'; but I have always thought some of them better than 'curl,' as curl seems to me to involve the idea of either a helix or a flat spiral. I see I was wrong in attributing 'curl' to Clifford. He gives a good many such words, but it was, as you say, Maxwell that first gave *curl*, as he in fact tells us himself in the first volume of his *Electricity and Magnetism*. It is rather the symbolic system connected with it in your own and Maxwell's papers that I object to, than the word itself, and I cannot agree with any attack on Cartesian coordinates. All words that help us out of aphasia, provided they promote clearness instead of the reverse, are to be welcomed. . . . We want a thorough mechanical theory which shall include the undulatory theory of light with electrostatics, and electromagnetic force, and electromagnetic induction, with the *mobility of the medium and all the bodies concerned*, which is part of the essential nature of the affair.

Yours very truly,
William Thomson."

The problem of calculating the effective resistance of the inner conductor of a concentric cable was approached by Maxwell (*Electricity and Magnetism*, Vol. II, p. 690) for low frequencies, and only for a few terms of a series. Heaviside considered the whole "throttling" effect, i.e., the effective resistance, the effective inductance, and the tendency to surface concentration (*The Electrician*, May 3, 1884, p. 583), using two functions, M and N, which Kelvin later called the "ber" and "bei" functions. Heaviside developed this study (*The Electrician*, January 3, 1885), and Alexander Russell elucidated and extended it in a valuable review of the state of knowledge of the matter (*Proceedings of The Physical Society*, Vol. XXI, Part VI, December, 1909).

The date of an event of some consequence—a visit by Hertz to England—is recorded in a letter written on November 24, 1890, by Professor Ayrton.

"Dear Mr. Heaviside,

Professor Hertz is coming to stay with me for two or three days at the end of this week, and on Sunday some friends who are interested in electromagnetic radiation are coming to lunch with us to meet Professor Hertz. If by chance you will be in London Sunday next the 30th inst., we shall be delighted if you will come to lunch with us.

Sincerely yours,
W. E. Ayrton."

It is safe to assume that Heaviside was not present. Three years later Ayrton wrote to him for a definition of inductance, and on January 25, 1896, he again asked him for assistance in calculating the size of a copper plate to represent, in metal, the sea. At that time an endeavour was being made by electricians, who consulted Ayrton, to estimate the practicability or otherwise of telegraphy from the shore to a light ship.

They knew that, owing to the swinging of the ship with the tide, a cable could only with difficulty be taken on board. The plan was to place a large coil at the bottom of the sea. Through the coil an alternating current was to be sent from the land to act inductively on a similar coil in the ship. Ayrton also enquired of Heaviside how the current in the coil would be affected by the sea.

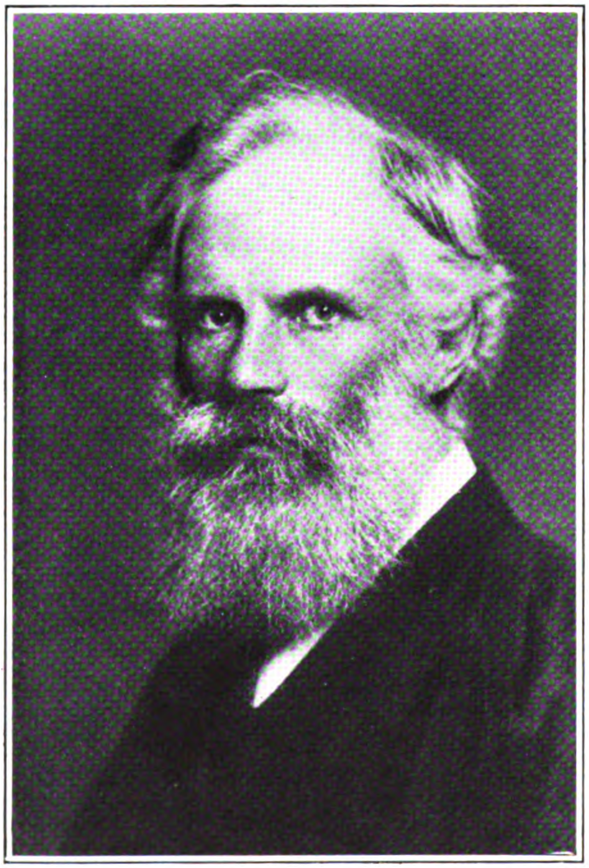


Figure 9—Professor George Francis FitzGerald.

In 1897 Heaviside was urged by a representative of the Northern Lighthouse Board to examine the proposal to utilise an induction coil and telephone in light ships to pick up signals from a corresponding coil at the bottom of the sea.

On March 8, 1905, a Cambridge mathematician wrote to him for a proof of the now familiar conjugate theorem that if a current, I, entering a solid object at A and leaving at B produces a difference of potential, V, between two other points, M and N, in the body, then a current I entering at M and leaving at N produces a difference of potential V between A and B.

His views on electrical matters were also requested by correspondents as distantly scattered as Mandalay, Calcutta and Alleghena.

The knowledge possessed by him of phenomena relating to submarine cables, and his profound study of mathematical principles relating thereto, enabled him to impart new life to a world of electrical communication that, in essentials affecting construction, had remained, for about thirty years, dormant. His advocacy of "loading" was not at first received with favour in his own country. For telegraph cables, Kelvin—recognising the analogy between electrical transmission and the diffusion of heat, examined by Fourier—had developed the "K R" law and had shown how to draw arrival curves for the case of a cable devoid of inductance and leakance, when both ends are put direct to earth. It was left to Heaviside to discover how to take account of inductance and leakance and how to develop equations to predetermine the effect upon the arrival current of the insertion of condensers and other apparatus at one or other or both of the ends.

It was also left to Heaviside to discover that there is a critical relationship between the four cardinal quantities—resistance, capacity, inductance, and leakance—in any telegraph or telephone circuit, and that, when this is fulfilled, received signals are an exact reproduction of those sent. He called this the "distortionless" condition—for his onomastic skill was unexcelled. He compared the case with that corresponding to greater inductance, and he exemplified the effects of reflection. His proposals for effecting improvement by adding inductance continuously, or in "isolated lumps," are described in *Electromagnetic Theory*, Vol. 1, pp. 444–446, where he sets forth his work of 1886–1887.

There is a marginal note in pencil on a stray reprint, that when he first suggested loading at a meeting of the Physical Society, a well-known physicist, Blakesley, at that time said, "it would be like making humps on a road to increase the speed of vehicles."

In common with all pioneers his mind turned at last to the question of the structure of matter;

here is a fragment, so far as is known, unpublished:

"There are wheels within wheels, and the elementary volume itself may be a highly complicated dynamical structure with various sorts of energy in it, determinately connected with the external world. Nor is this mere mathematics. It seems to me that the state of things suggested is very likely that which prevails in the universe of molecules. The usual mathematics of continuous actions through elastic media takes matters in the gross. The unit volume must be large enough to contain an enormous number of molecules. The first approximation to a molecule is a little lump of matter banging about, exchanging its momentum and energy with its neighbours. But the molecule itself may be a little world, and on magnification, its affairs may be as complicated and important as those in our world. There is no absolute scale of magnitude in matters of length and time. Those wonders of wonders, thought and reason and memory, probably involve an inner mechanism of the atoms, especially as regards the storage of ideas involved in memory, to be lost sight of for long periods. Extremes meet, and the fast decaying brain of the old man brings to the surface the events of child life. The fact that the brain is subject to material change and replacement during life does not debar the theory of partial dependence upon the inner world of the atom. The replacement tends to follow established lines more or less perfectly; usually less, of course. We do not want a special kind of "mind-stuff." In any case, I cannot conceive the possibility of such a thing as long continued memory on the lines of mere external chemistry, and averages of molecules. It must depend on something deeper. Carlyle said: 'Go deep enough, there is music everywhere.' This dogma would perhaps have more truth in it, if for music were substituted 'thought.' At any rate, it is potentially existent in all matter which can go to make the man . . . how is it that early impressions sink deeper and deeper becoming harder and harder to recall, and come to the surface again only in old age? It looks as though they worked themselves in deeper and deeper into the atomic mechanism. At any rate, I can construct by ordinary magnetic coils and electrical condensers an arrangement which shall imitate this absorption and subsequent recovery—I do not refer to hysteretic condensers, but ideally perfect ones, the explanation of hysteretic condensers is in fact similar—in a weakened form, returning after many days like the bread that was cast upon the waters. If the inner parts of brain atoms are storage cells for very high frequency waves, if they are emitted they will sympathetically excite similar cells in other brains in an imperfect manner, and so provoke a vague impression, which the thinking part of the brain may develop to a picture. The power of emission may be great in strong mediums; receptivity will be small in a Huxley. Saints halos! Phosphorescence! Why not? they were funny fellows."

Elsewhere, in a marginal note, he expressed the same idea more concisely, but with less reasoning:

"Life is an essential property of matter. All matter is alive, even the deadest. All phenomena are natural phenomena."

Only once amongst his papers is there found any trace of an attempt to write a story. It is entirely devoid of romance, and takes the form of a sketch entitled "Muscular Characters." It refers to his visits to a public gymnasium at the "Pimple"—presumably Primrose Hill—and his impression of youths who resorted there. And once, only once, is there any trace of his having descended into verse. The occasion was the dedication of Volume 1 of *Electromagnetic Theory* to the children of his brother Charles. He speaks of his nieces and nephews as "My dear Children." The verses are written in pencil on the fly-leaf of a copy he presented to Charles:

DEDICATION.

To MY DEAR CHILDREN.

1. I did not send you any cards,
   For I had none to send,
So now I send you this here book,
   Whereby to make amend.

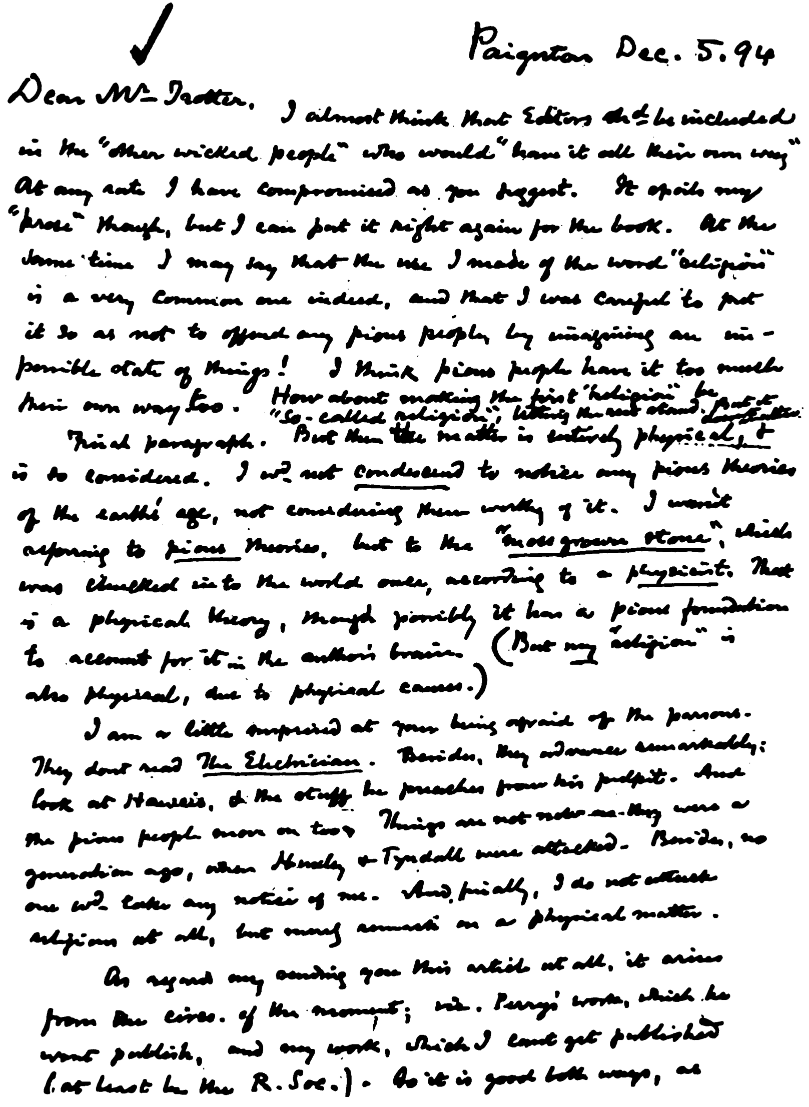
2. The first chap. is for Freddie,
   And may he always be,
A credit to his parents,
   And an ornament to Torquay.

3. The next chap. is for Ethel,
   And may she read it well,
And study it, and find it good,
   Nor think the book a sell.

4. The third chap. is for Charlie,
   And may he *never* be,
A terror to his parents,
   And a torment to Torquay.

5. The fourth chap. is for Rachael,
   Because it is the best,
And may she never *never* try
   To turn it into jest.

6. The preface is for Beatrice,
   Because it is so short,
And may she never *never* think
   It all amounts to nought.



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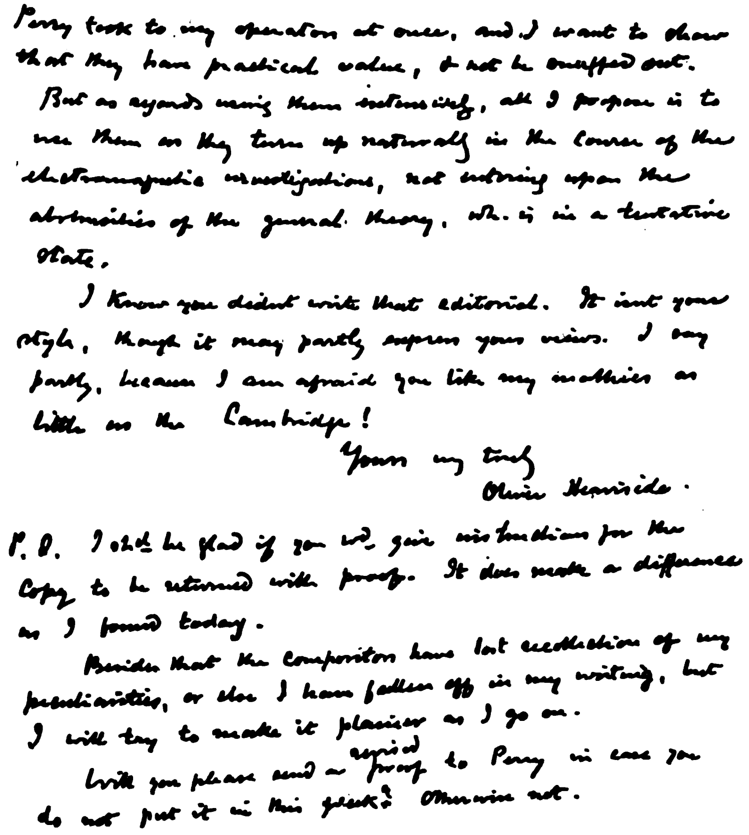
Paignton Dec. 5. 94

Dear Mr. Trotter. I almost think that Editors sh^{d} be included in the "other wicked people" who would "have it all their own way". At any rate I have compromised as you suggest. It spoils my "prose" though, but I can put it right again for the book. At the same time I may say that the use I made of the word "religion" is a very common one indeed, and that I was careful to put it so as not to offend any pious people by imagining an impossible state of things! I think pious people have it too much their own way too. How about making the first "religion" be "So-called religion", letting the rest stand. [illegible]

Third paragraph. But then the matter is entirely physical, & is so considered. I w^{d} not condescend to notice any pious theories of the earth's age, not considering them worthy of it. I wasn't referring to pious theories, but to the "moss grown stone", which was chucked into the world once, according to a physicist. That is a physical theory, though possibly it has a pious foundation to account for it in the author's brain. (But my "religion" is also physical, due to physical causes.)

I am a little surprised at your being afraid of the parsons. They don't read The Electrician. Besides, they advance remarkably: look at Haweis, & the stuff he preaches from his pulpit. And the pious people were on top. Things are not now as they were a generation ago, when Huxley & Tyndall were attacked. Besides, no one w^{d} take any notice of me. And, finally, I do not attack religion at all, but merely remark on a physical matter.

As regards my sending you this article at all, it arises from the circs. of the moment; viz. Perry's work, which he won't publish, and my work, which I can't get published (at least by the R. Soc.). So it is good both ways, as



Perry took to my operators at once, and I want to show that they have practical value, & not be snuffed out.

But as regards using them extensively, all I propose is to use them as they turn up naturally in the course of the electromagnetic investigations, not entering upon the abstrusities of the general theory, wh. is in a tentative state.

I know you didn't write that editorial. It isn't your style, though it may partly express your views. I say partly, because I am afraid you like my [illegible] as little as the Cambridge!

Yours very truly
Oliver Heaviside.

P.S. I sh^{d} be glad if you w^{d} give instructions for the copy to be returned with proof. It does make a difference as I found today.

Besides that the compositors have lost recollection of my peculiarities, or else I have fallen off in my writing, but I will try to make it plainer as I go on.

Will you please send a revised proof to Perry in case you do not put it in this week? Otherwise not.

Figure 10—Specimen of Oliver Heaviside's Handwriting. This communication was addressed to Mr. Trotter, who in 1894 was editor of *The Electrician.*

7. The Contents are for Pa and Ma,
And may they never know,
The pangs of tortured conscience,
Or the awful depths of woe!
Jan. 1, 1894.

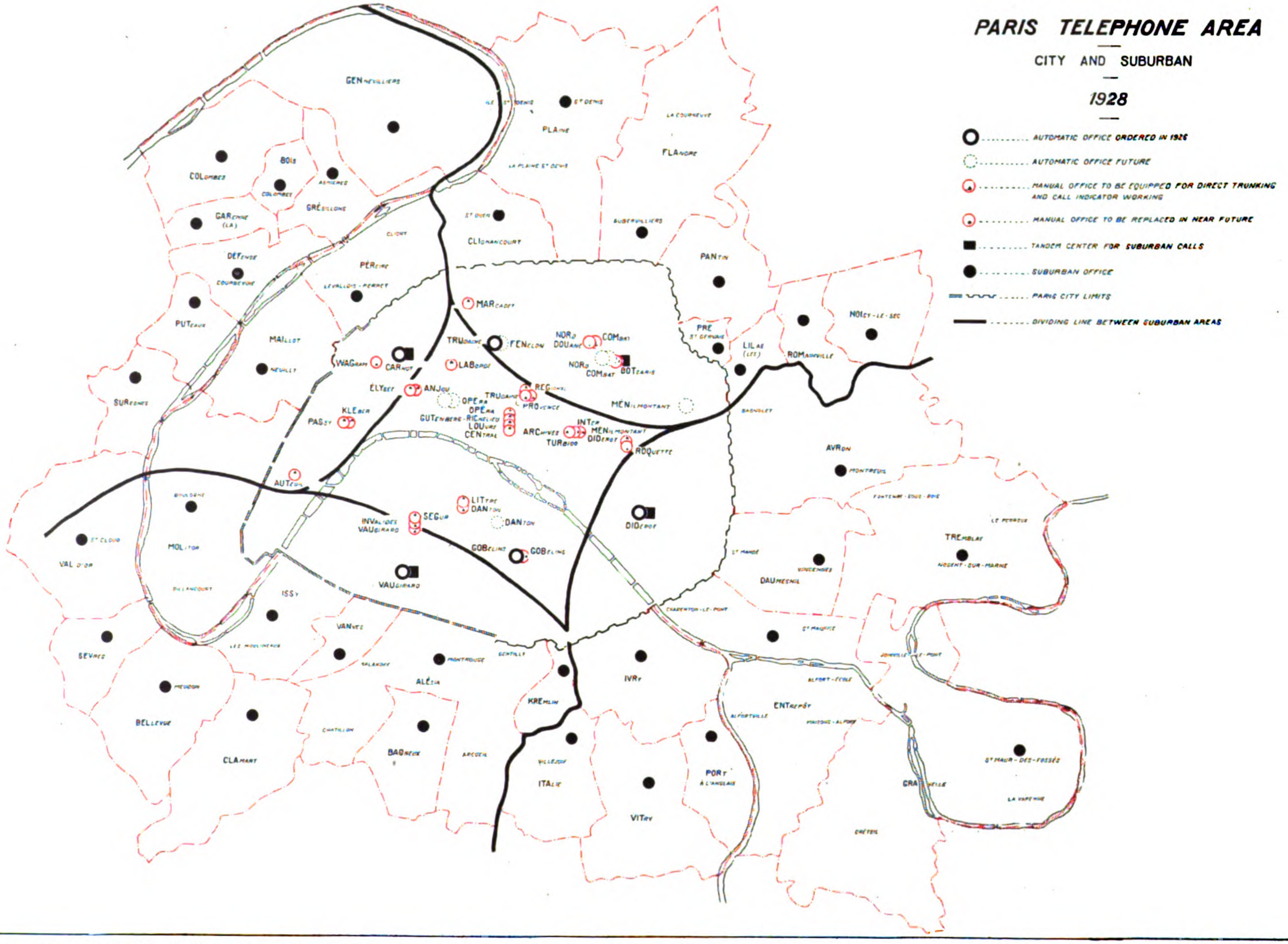
Amongst the fragments also is this:

> "Here we may stop to remark on the immortality of the soul. This doctrine, which probably had its first origin in the dreams of savages, survives all attempts to abolish it. In its old fashioned sense the principle may have already lost its hold upon a great many men and women of the highest attainments, and may be mostly held by those who are least capable of judging, as an article of unthinking and unquestioning faith. But it is part of human nature for all that. When old beliefs are found out of keeping with the spirit of modern knowledge, the proper way is not to abolish them, but to modify their interpretation. Now there is a far nobler sense in which the doctrine of the immortality of the soul is true, not as a matter of faith, but of fact. Everyone in living his life is making the world for those who will follow. Everyone makes some impression on the world, good or bad, and then dies. The good or the mischief he has done remains; the impression is left for all time. Not only the lives of those around us, but of our followers, are modified in consequence of our actions. The aspirant to immortality who is dissatisfied with the old conventions may then cry 'Non omnis moriar.' A part of us lives after us, diffused through all humanity more or less, and all Nature. This is the immortality of the soul. There are large souls and small souls. The immortal soul of the scienticulist is a small affair, scarcely visible. Indeed its existence has been doubted. That of a Shakespeare or a Newton is stupendously big. Such men live the best part of their lives after they are dead. Maxwell is one of these men. His soul will live and grow for long to come, and hundreds of years hence will shine as one of the bright stars of the past, whose light takes ages to reach us."

To remove misapprehension it should be recorded that Oliver Heaviside was neither destitute nor in desperate poverty. Financial troubles came to some extent because, throughout his career, he was devoid of business acumen. He refused much that life had to offer him—even medical attendance in his illness. From several directions his friends approached to offer amelioration. Some of the astutest intellects of his country conspired to find a way of supplying him with funds in a manner that he might not resent. They succeeded only in part. At the back of his mind was the complexity that he ought to have received from the commercial world early acknowledgment and remuneration for his work in telegraphy and telephony. He suffered, as many an inventor has, to see that the prize had slipped from his grasp into other hands. That being lost, he preferred to live in his own way. Yet one compensating delight he had: the sense of supremacy in his own domain of mathematical physics. This supremacy was derived primarily from his powers of intuition—exceptionally developed, almost unfailing, and ever inspiring. Heaviside penetrating towards an immortal generality can only be compared with Faraday prospecting for eternal truth in a wilderness of experimental facts.

He detested alcohol in all its forms, but he was an inveterate smoker—a pipe of the strongest tobacco was his delight. At Homefield, in the years 1913–1914, he scarcely ever went beyond his garden. If his friends gained admission, they were gladly received and they found him entertaining, jocular, and still a tease. In 1921 he was less accessible. By 1924 he had increased his troubles by getting at loggerheads with local authorities concerning accounts. During the last years of his existence he dwelt alone. He purchased supplies of food and other necessities through the kind voluntary services of Constable Henry Brock, a worthy representative of the Devon County Police, who refused all remuneration from him.

At about that time his health rapidly failed, for pneumonia intervened with other complications. In January, 1925, after a serious attack of illness, he was removed to a nursing home, where on February 3, 1925, he died, at the age of 75 years. He was buried in the grave of his father and mother in the Cemetery of the Urban District Council, at Paignton.



Frontispiece—Plan of the Paris Telephone Area, showing the city proper and the surrounding suburban area which has been brought into the automatic switching scheme. The first three letters of the office prefixes shown in large type are those which the subscribers will dial.

The Rotary Automatic Telephone Introduced Into Paris

By G. DEAKIN

Vice President and Technical Director, Le Matériel Téléphonique

Introduction

THE first step in the actual conversion of Paris from manual to automatic operation was brought to a successful conclusion on Saturday night, September 22d, on which date approximately 3500 working lines were transferred to the new Rotary automatic office, Carnot.

The study of the Paris telephone requirements was begun by the French Telephone Administration a year or so before the outbreak of the World War. What, up to that time, had been considered a necessity, became a luxury and it was not until 1924 or the early part of 1925 that the study was again seriously taken up. This unavoidable delay was not entirely without advantage. It gave the Administration the opportunity to study the methods and systems which had been chosen by other Administrations and to profit by the experience gained by these Administrations in the operation and exploitation of the chosen systems.

The French Government was not slow to take advantage of this opportunity. It appointed two committees, one a technical committee and one a general committee, to study the telephone requirements of the city of Paris and to determine what system would best meet these requirements. The technical committee made a thorough study and investigation of all of the major automatic systems then in operation in Europe and on July 27, 1925, the Government issued a *cahier de charges* calling for tenders for the manufacture in France and the installation of automatic equipment for four 10,000 line offices.

With the additional data gained from the resulting tenders, the two committees again examined the subject and the pros and cons of all systems. In the end, the two committees unanimously chose the Rotary system for Paris and on October 14, 1926, the contract for the first four offices was awarded to Le Matériel Téléphonique. The contract carried with it the proviso that standard Rotary apparatus shall be employed throughout and that the circuits shall be designed by Le Matériel Téléphonique, to meet the requirements of the Administration and that the full responsibility for the successful operation of the system under normal and specified conditions shall rest with Le Matériel Téléphonique.

Paris Telephone Area

The Paris telephone area as now planned for automatic working is illustrated in the frontispiece to this paper. It comprises the solidly built up and densely populated city proper within the now obsolete fortifications and the variously settled and populated suburban areas which surround Paris on all sides. These suburban areas vary from highly industrial to almost entirely residential.

The city proper is now served by twenty-two manual switchboards located in fifteen buildings, in addition to the new Carnot automatic office.

The suburban area is served by fifty-seven manual offices, some very small. This number will be reduced to thirty-seven as indicated in the frontispiece. Each of these thirty-seven ultimate suburban office centres has been assigned a prefix suitable for automatic working. These prefixes are now in use, one prefix often applying to two or more offices. To distinguish between towns having the same prefix, the subscribers in such towns are allotted numbers in different thousands, thus enabling the answering operator to distinguish the office by the numerical suffix.

The total telephones in Paris and the suburbs are about 340,000.

Manufacturing and Installation Accomplishments

Carnot at the present moment has equipment installed and tested for 6,000 lines and additional equipment in process of installation for another 4,000 lines, which will bring the total equipment up to 10,000 lines. The contract required the completion of the first 6,000 lines in twenty-one months; that is, by July 14, 1928. This date was kept. The requirement for 100 per cent French manufacture also was met.

As the original factory premises at 46, Avenue de Breteuil were entirely inadequate for a large automatic programme, a new factory was built on the Company's property in Boulogne, just outside of Paris. Work on the first quarter section of the new building was started in May, 1925, and the work on the last section is just now being completed. The great effort made by the shop to build up a personnel, which grew from about 1,500 to 5,000 in less than a year, and to construct the necessary special tools for the manufacture of the automatic equipment, is a story by itself.

The installation in Carnot of the first piece of automatic equipment took place December 23, 1927. Between that time and July 14, 1928, some 750 cabled and combined bays have been placed in position, cabled, wired and tested, including tests with the junction equipment to and from the various manual offices—a considerable achievement in view of the fact that the Installation Department recruited most of its staff from green help. The following log may be of interest:

View of the Telephone Building. The wing which contains the new Carnot Exchange is at the rear of the building and runs parallel with the street.

October 31, 1927—Installation of switch racks at Carnot started

December 23, 1927—First automatic selector bay received

February 18, 1928—First combined bay received

March 25, 1928—Installation estimated to be 50 percent complete

May 12, 1928—First semi-B call sent through

May 25, 1928—First automatic to automatic call sent through

June 26, 1928—First call sent via tandem call indicator position to a manual office

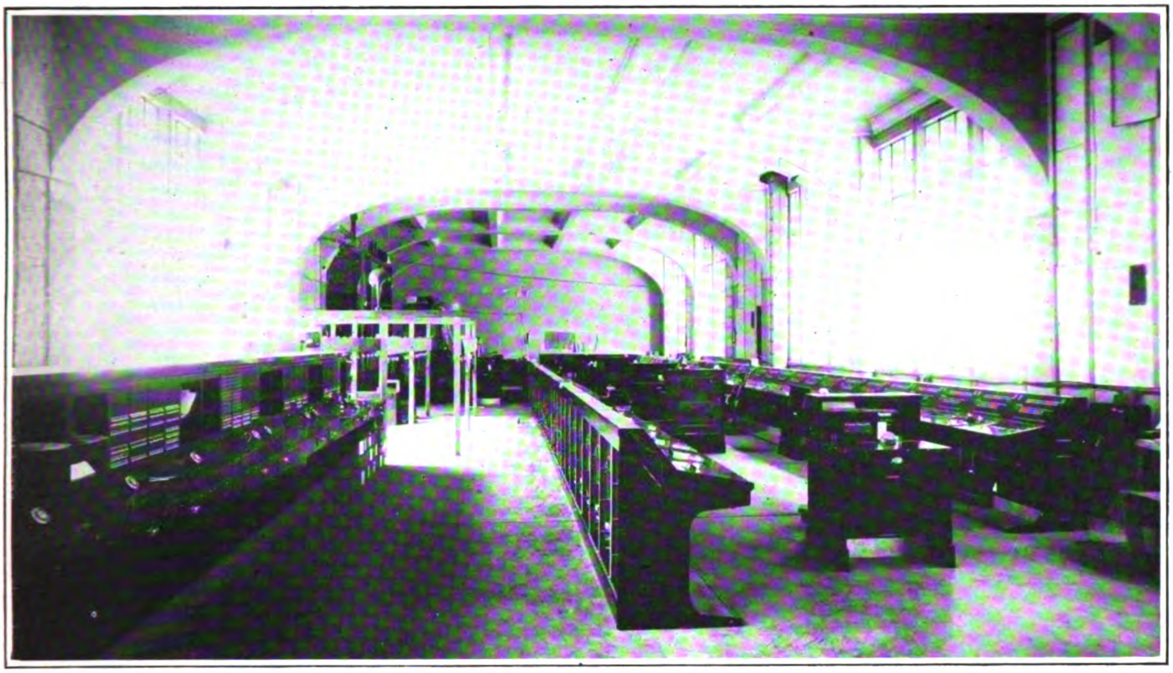
Description of Equipment

The Carnot office occupies four floors of a newly constructed wing of the telephone building at 27, Rue Guyot. The power plant is in the basement and is of the continuous float type. A single battery potential of 48 volts is used for all purposes except for metering, for which purpose a booster battery of 70 volts is supplied.

On the first floor are two main distributing frames, one for subscriber lines and the other for junction lines. These frames may be extended to accommodate a second 10,000 line office. On this floor are also the service meters, the wire chief's desk and the register and junction equipment exclusive of the selectors for the temporary semi-B and tandem call indicator positions.

The second floor contains the manual operating room, the incoming third selectors, the out junction test panel and the junction intermediate distributing frame. The operating room contains thirty-five semi-B positions, thirty-eight tandem call indicator positions, information and complaint positions, toll switching positions and the usual supervisors' and chief operator's desks.

The third floor is devoted exclusively to automatic equipment and accommodates all of the automatic equipment with the exception of that



Carnot Operating Room. At the right are thirty-eight call indicator positions and in the center, thirty-five semi-B positions. At the extreme left is the information desk. In the distance is the manual toll switching section. The temporary structure in the middle was erected for supporting the test telephones.

previously referred to on the first and second floors.

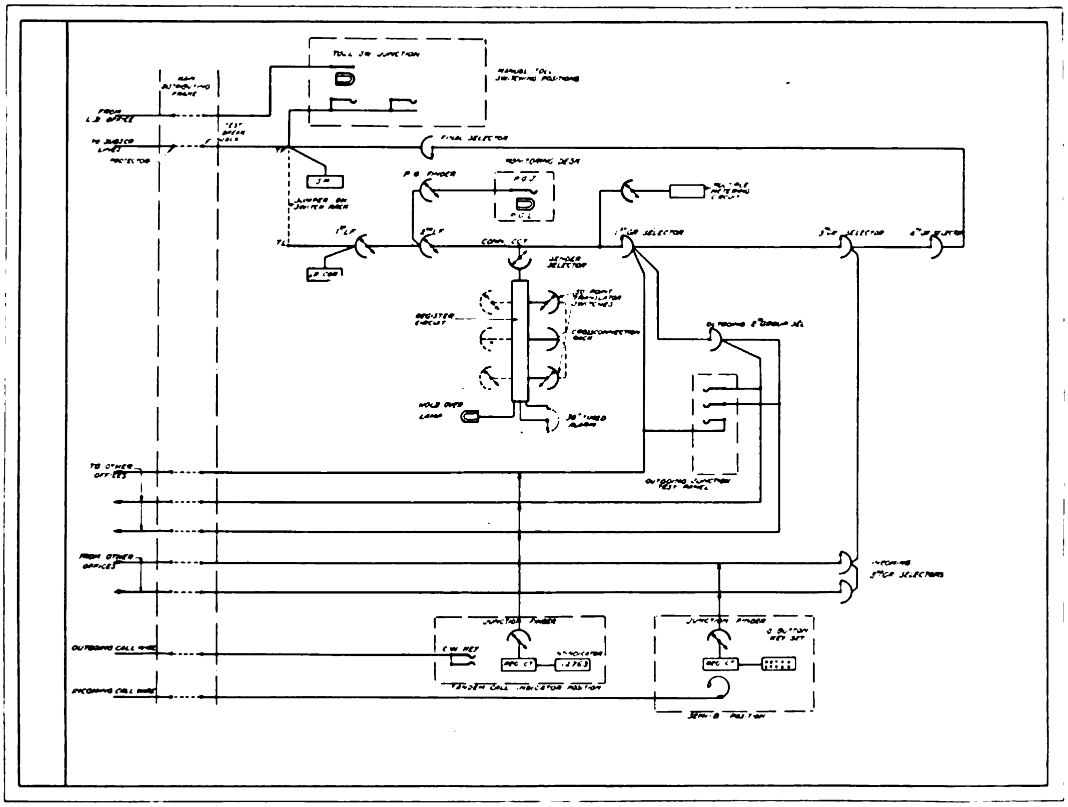
Except for the arrangement of equipment, all Paris automatic offices will be alike. An idea of the equipment involved may be had by reference to the accompanying junction diagram, which shows the general arrangement of the equipment for Carnot.

The outside cables terminate on protectors of the usual type. The switchboard side of the main distributing frame is fitted with test break jacks, which experience in Europe shows are a great help to the wire chief, since they permit the line to be picked up by a line number and not by a cable number which requires reference to a cable record. The use of test break jacks also obviates trouble at the protector due to the unavoidable disturbance of the heat coils and carbon blocks by the insertion of a test shoe into a protector.

The test break jacks are cabled to terminal strips placed on top of the switch racks immediately above the final selector bays. On the same switch racks adjacent to the final selectors are the first line finder bays which also accommodate the line and cutoff relays. Jumpering between the two sets of terminal blocks makes the use of a separate intermediate distributing frame unnecessary. Main and P.B.X. lines may be mixed at will, thereby making it possible to more or less uniformly distribute the traffic and thus to avoid the necessity of having an unduly large number of selectors in certain groups.

The service meters are cabled to the switchboard side of the main distributing frame. The meters are of the multiple metering type, similar to the well-known standard meter, but equipped with a differential winding to cause the meter armature to restore to its normal position when the operating booster potential is removed.

When a subscriber calls, his line relay is energised, whereupon the associated group of first line finders hunts for the calling line. The first to reach the calling line makes it busy, whereupon the associated group of second line finders forming part of the connection circuits hunts for and selects the first line finder. Immediately following this the sender selector of the connection circuit hunts for and selects a free register. All this normally takes place on an average in one half to one and one half seconds, the average generally being nearer to one half a second than to one and one half seconds.

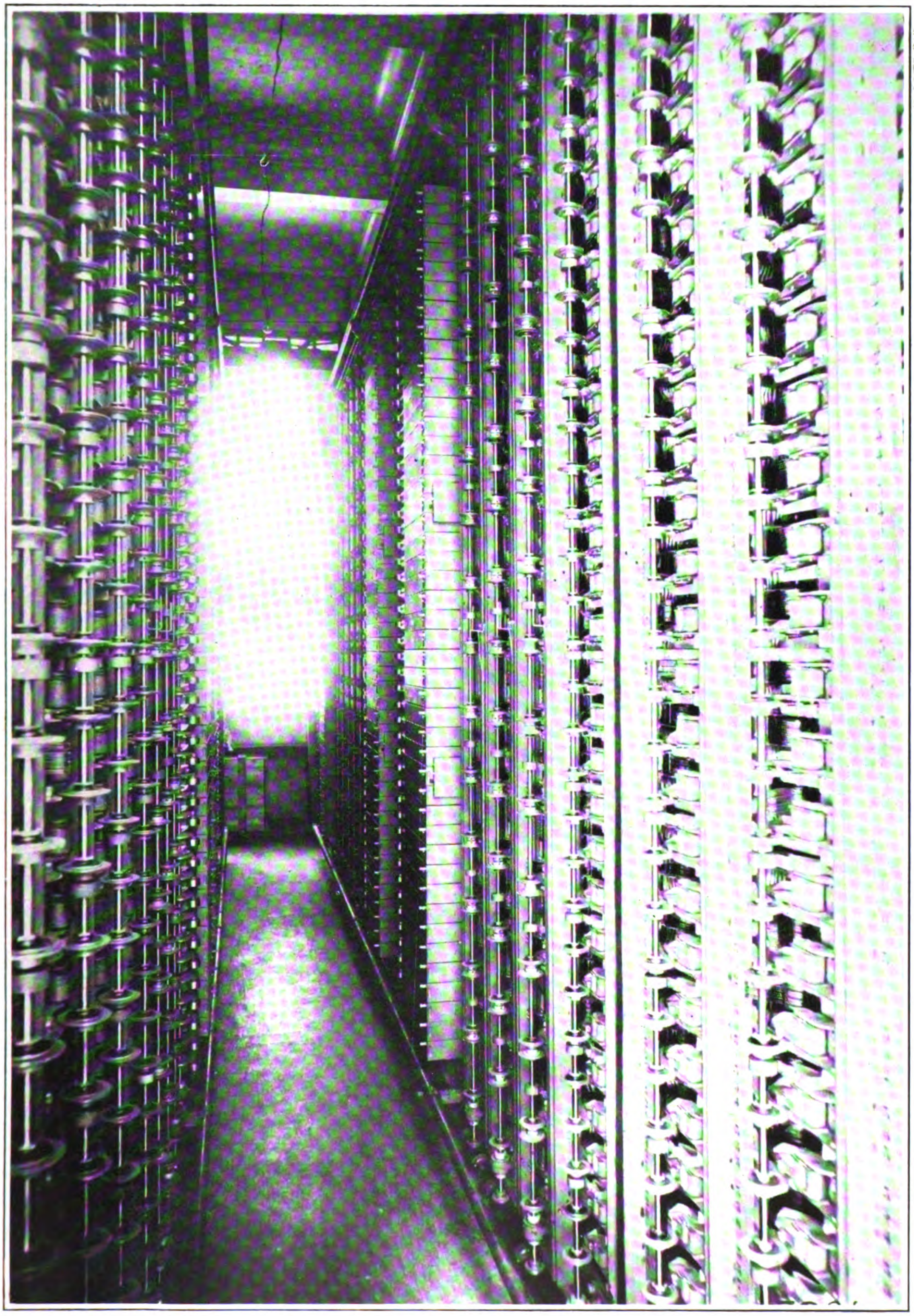


Junction Diagram, Carnot Office.

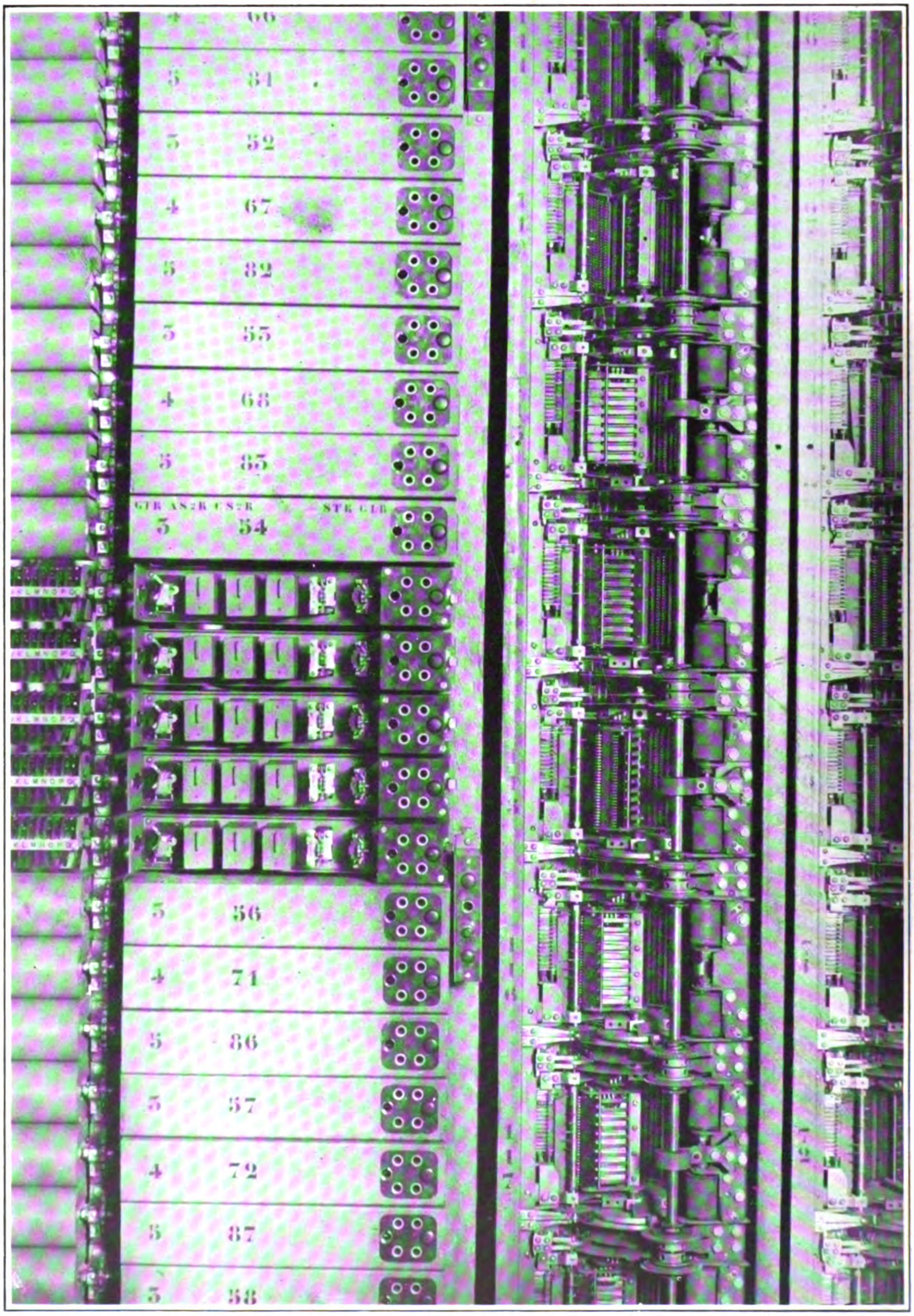
The subscriber now dials the three first letters of the wanted office and then the four figures, regardless of whether the wanted number is in the city or in the suburbs. When the first office code letter is dialed the translator switch, which forms part of the register circuit, hunts for the first letter position and stops provisionally on the first office prefix position commencing with the letter dialed. When the next two letters have been dialed, the translator switch hunts for the wanted office prefix, the maximum delay after dialing the third digit being about one half a second. The flexibility of the system permits all office prefixes beginning with the same letter to be grouped together thus permitting, as just indicated, a partial selection to be made before the completion of the dialing of the office prefix. When the wanted position is found, the first, the second and tandem selectors are caused to extend the connection. When the first of the four figures is dialed, the selection may be extended to the third selector and when the second figure is dialed, to the fourth selector. When the third figure is dialed, the trip spindle of the final selector may be set and when the fourth figure is dialed the brush carriage may select the wanted line.

For the time being calls from Carnot to all other offices pass through tandem call indicator positions located in Carnot. The number dialed appears on a number indicator before the tandem operator whereupon the operator passes, by means of an order wire, the wanted number as well as the junction number to the associated *B* operator in the wanted office. This practice was adopted for the cutover of Carnot, since time did not permit the installation of permanent call indicator equipment in those manual offices which are to remain. The manual end of the present tandem junction is in reality a standard manual *B* junction circuit with a relay added to obtain the required control.

Incoming calls to Carnot for the time being are made through order wire semi-B positions, the *B* positions differing from those previously made by Le Matériel Téléphonique in that the register



View of Aisle Between Rows of Finished Connection Circuits.



Front View of an Incoming Third Selector Bay and a Portion of the Associated Combined Bay. The incoming third selectors, without change, may be associated with any of the various manual offices in Paris and with other automatic offices. The character of the out-junction equipment thus remains unaltered regardless of the type of the distant office. In Paris, there are five or six distinct types of manual offices of four different makes.

circuit is substantially the same as that which will be installed in the manual offices for direct trunking to automatic.

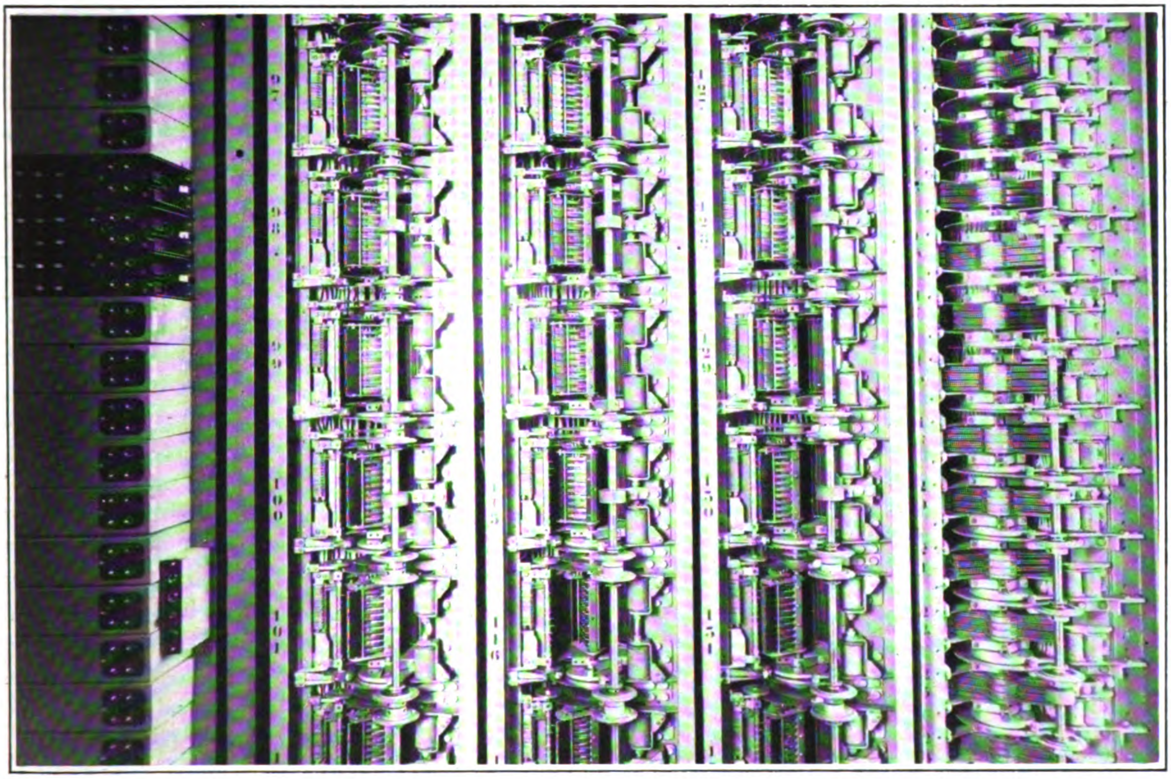
The arcs of the first group selectors are cabled through various distributing facilities direct to the main distributing frame, to a sufficient number of groups of outgoing second selectors to obtain the required out junction paths, or direct to third selectors. This arrangement is shown on the junction diagram. The local and incoming third selector arcs are cabled in multiple to the fourth selectors. The fourth selector arcs are cabled to the final selectors.

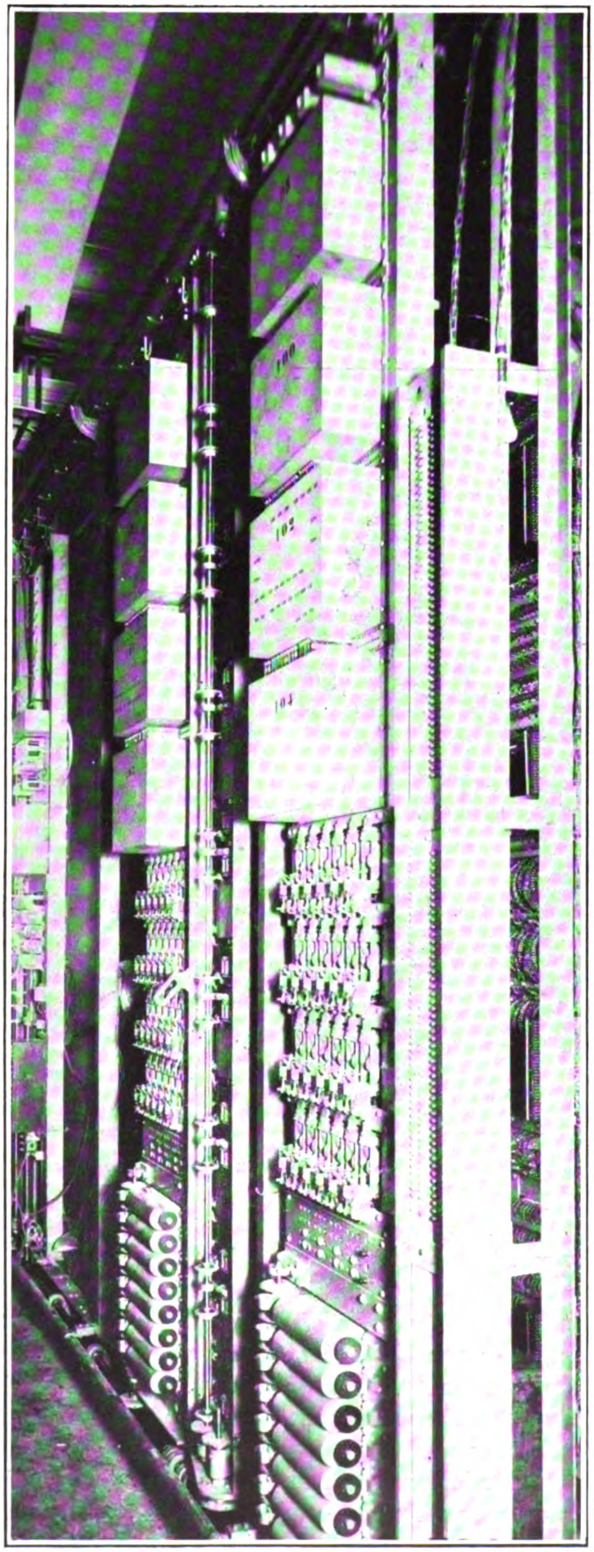
The incoming third selectors are of the universal type. They may, without change but with suitable simple cross connection properly provided for, be connected to an incoming junction from another automatic office, to an incoming junction from a manual office equipped for direct trunking, or, as at present, to an incoming junction from a manual office served by a semi-B position.

The fourth selector circuit differs from those previously used in the Rotary system in that it contains the ringing relay and ringing and busy tone facilities.

The final selector is of the universal type and may be used indiscriminately with main or P.B.X. lines. Any group of adjacent lines in any final arc may be adapted for P.B.X. working by the simple procedure of shunting the *C* wires of the first and last lines in the group with resistances. The function of the first resistance is to cause the final to hunt in case the first junction is busy. The function of the second resistance is to cause the final to stop hunting in case all junctions in the group are busy. The final always functions as a main line final when no shunt resistance is used.

Grounded lines are automatically transferred to the monitoring desk after a lapse of 30 seconds. A P.G. (permanent glow) finder picks up the first line finder and lights a lamp on the monitoring desk. The connection circuit and register


Front View of Three Connection Circuit Selector Bays, a Portion of a Combined Relay and Sequence Switch Bay to the Left and a Sender Selector Bay at the Right.



Two Register Bays with the Common Translator Bay in Between Are Shown in the Foreground. Each register bay accommodates four register circuits.

are then freed. Failures to complete dialing are also automatically transferred to the monitoring desk after a lapse of 30 seconds counting from the last dialing of a digit. The monitor may plug into the P.G. jack and test the line or he may speak to the calling subscriber if there is one.

With each group of connection circuits are associated a few multiple metering circuits. These are brought into action at the end of a successful multi-charge connection, the register having previously signaled this fact to the connection circuit. Single meterings do not involve the multiple metering circuit. The connection circuit automatically takes care of such meterings.

All out junctions pass through a test panel by means of which a quick test may be made of each junction. With each jack is associated a push button key, which, when thrown, makes the junction appear busy at the outgoing end.

Any two wire junction may be made busy at the incoming end by opening the fundamental circuit by removing the ground from the *A* wire. The first and second selectors make two tests, first a test of the *C* wire to ascertain whether or not the junction is free at the outgoing end and then a test of the *A* wire to ascertain whether or not the junction selector is in its normal position at the incoming end. If either of these tests show the junction busy or off normal the selector passes on without stopping to the next junction.

Should a properly dialed call fail to go through for any reason whatsoever, the calling subscriber is automatically freed after a lapse of 30 seconds providing he waits at his telephone. The register circuit, the connection circuit and any other circuits involved in the incomplete connection are held and the "hang up" signaled to a switchman.

The routine testing facilities provided for the Carnot permanent equipment are very complete and fully automatic in operation. The major circuits are divided into convenient groups or by switch racks, and one routine test circuit is provided for each group or switch rack. A routine test circuit selects the circuits to be tested one at a time and puts them through a complete series of cycles, checking all of the essential features. When a fault is found the routine test circuit stops and automatically signals the attendant.

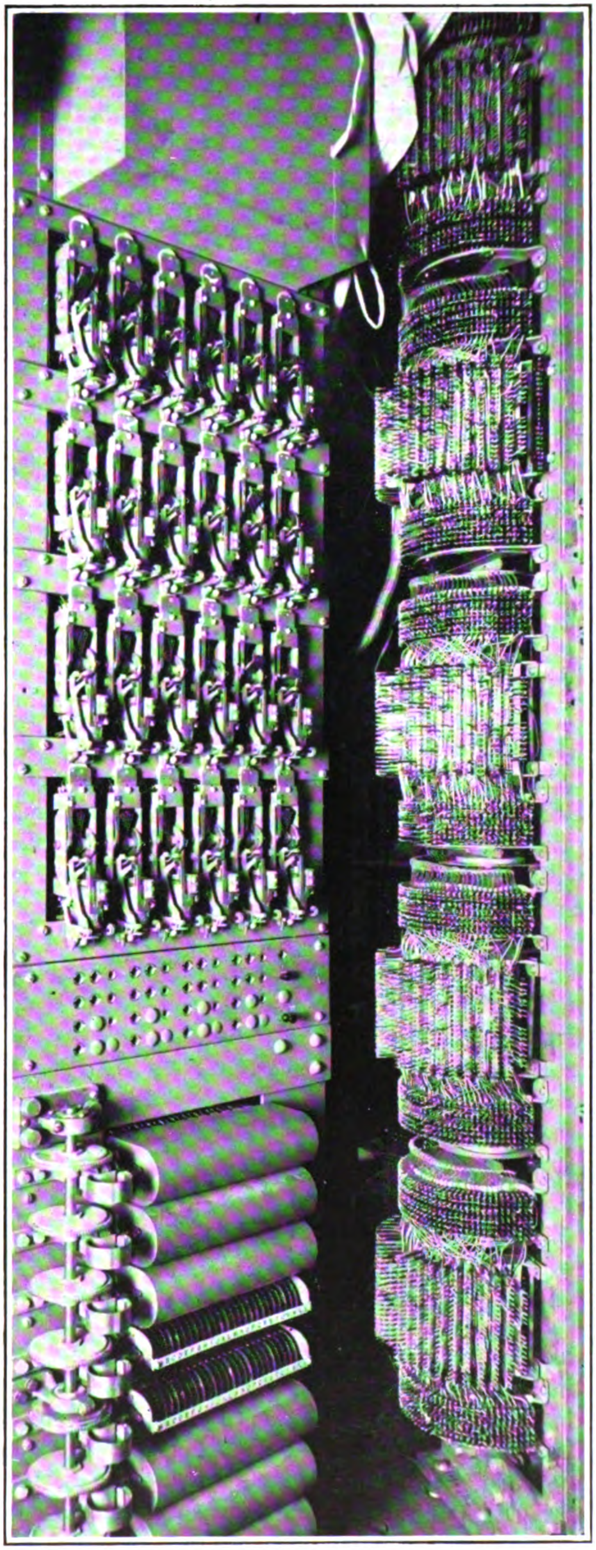
By inserting a wooden plug into the test jack which is associated with each circuit, the routine test circuit may be permanently attached to that circuit and the tests repeated indefinitely. Each routine test circuit includes a service meter to record the number of complete tests made.

Automatic routine test circuits permit the attendants to be non-skilled. The duties of the attendants are merely to record the time of stoppage, the number of the faulty circuit, the position it stopped in and the position of the routine test circuit. A ticket with this data is made out and handed to a skilled mechanic who repairs the trouble.

Three traffic observation positions are installed in Carnot and similar equipment will be placed in all other automatic offices. A single contact jack is installed on these positions for each second, third and fourth selector and by means of these jacks and associated cord equipment, the traffic passing over any group of junctions may, without trouble, be accurately determined. No group of associated junctions exceeds 150; that is, grading or inter-mixing is not extended beyond this figure. Each position may record 150 junctions simultaneously. A smaller number of junctions may also be supervised. The method of recording traffic with these facilities is as follows:

A plug is inserted into the jack of each junction forming part of the group to be observed. When the plugging up is complete, all meters are read or photographed and the starting key thrown. The time is recorded. At the end of the observation period, usually an hour, the starting key is restored, whereupon all meters cease operating. The new readings are taken or photographed. The difference between the two sets of readings gives the following information:

1. Total number of calls, completed or otherwise.
2. The time in two second intervals that each junction in the group was occupied. This record permits one to determine whether or not certain individual junctions were underloaded and the common junctions overloaded or vice versa, etc. The re-



A Close Up View of a Portion of a Register Bay and Its Associated Translator Bay. At the bottom of each register bay are located the sequence switches. Next above are the control lamps and then the rotary step-by-step switches which receive the dial impulses from the subscriber. Above them are the controlling relays. The translator switch bay is hinged so that the rear of the bay may be swung out into the aisle for cross-connecting purposes. It is shown partially swung out. The attendant is not required to work on the bays from the rear. The jumpering may be seen between the translator switches and the semi-circular strip between them.

cords give an exact picture of the distribution of traffic by junctions.

3. The number of times all circuits in the group were found busy.
4. The total duration of the time in two second intervals that all junctions were engaged.
5. In addition to these meter records a recording milliamperemeter gives a graphic picture of the distribution of the load during the hour or observation period.

It was not thought necessary to duplicate this equipment for the first line finders, connection circuits, registers and finals. For these circuits totalizing or overflow meters are provided.

In addition to the totalizing meters for registers one meter is provided for each office prefix. Such a meter operates each time a call is made to the associated office. Thus the distribution of the total out junction traffic is automatically obtained.

General Engineering Problem

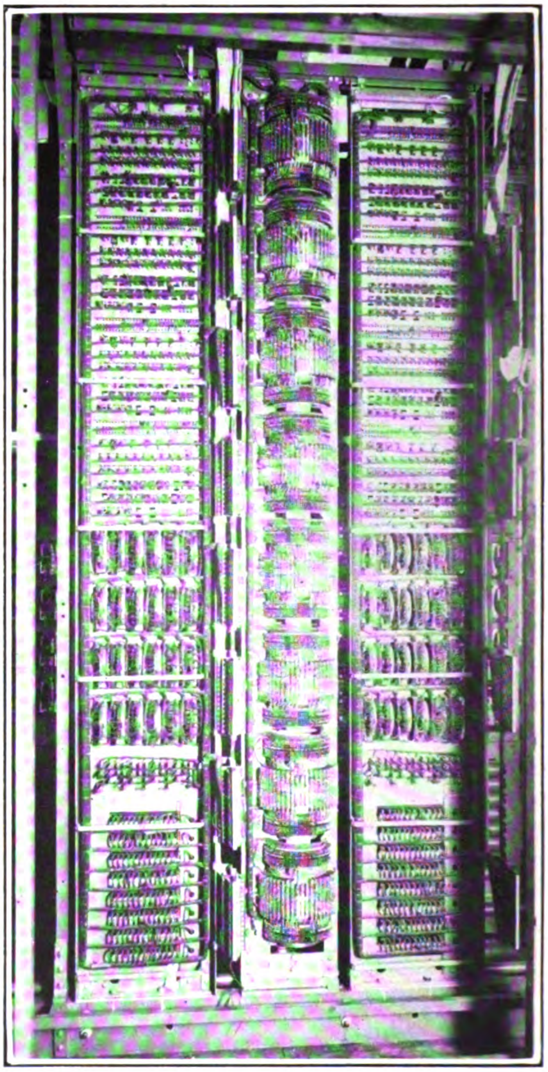
The preparation of engineering plans, and the design of circuits, particularly those for Carnot, could not be started until January, 1927. The time which had elapsed since the signing of the contract was devoted to a discussion of details with the engineers of the Administration. The *cahier de charges* previously referred to, had been prepared very largely to obtain information to enable the Administration to compare the relative merits of the different systems and to make their choice of a system, and was not, therefore, of much use in preparing working plans.

Four classes of telephone service are encountered in Paris—

City service,
Suburban service,
Short haul two number service
called "regional,"
Long distance service.

In working out the final plans for Paris with the Administration, it was agreed that the *cahier de charges* would have to be departed from in a number of respects in order to meet the methods of operation desired by the Administration. It is not necessary to discuss the differences in this paper. It will suffice to outline briefly or to refer to the initial and ultimate methods of operation finally agreed upon; and in this connection the reader is referred to an article[1] by Monsieur Pocholle, on the transformation of the Paris area which appeared in a previous issue of ELECTRICAL COMMUNICATION.

The present full automatic system is planned to care for the city and surrounding suburban areas. It may, however, ultimately be extended should the Administration find such an extension desirable. The maximum switching capacity of



Rear View of Two Register Bays; and, in Between, the Rear View of the Translator Switch Bay, Including the Semi-Circular Terminal Strip. With each register is associated two translator switches and between them is a distributing strip by means of which the office prefix and junction routing may be varied at will.

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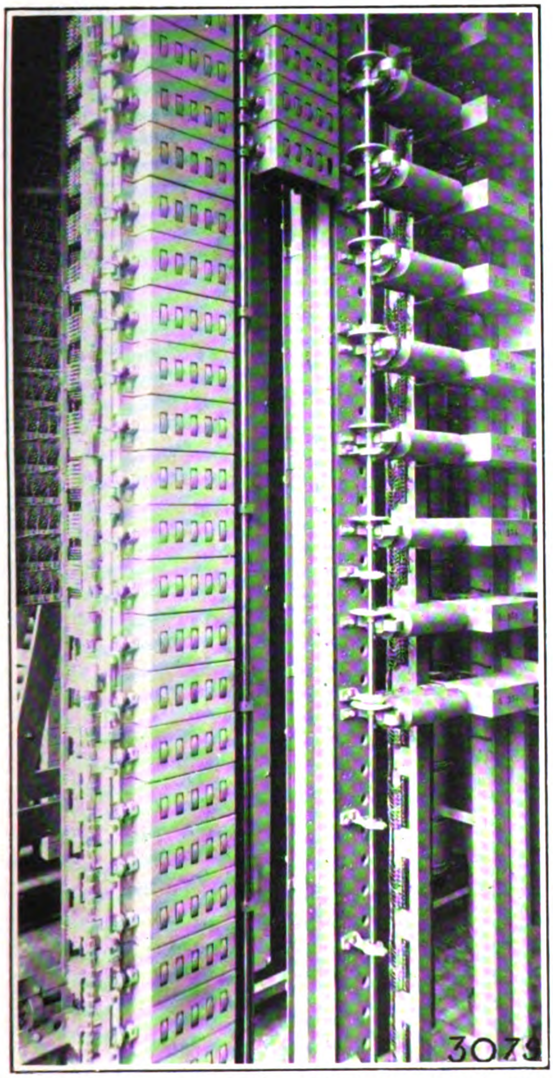
[1] "La Transformation du Réseau Téléphonique de Paris en Automatique," ELECTRICAL COMMUNICATION, Vol. 6, No. 3, January, 1928.

the present full automatic register circuits is 150 office prefixes, or 1,500,000 lines. Allowing for the impossibility of assigning every line, it may be said that the practical switching capacity of the present equipment is between 1,000,000 and 1,200,000 lines. It is estimated that the requirements in the next ten or twelve years will be about 400,000 lines. By the addition of translator switches to the register circuits or by increasing the capacity of the existing switches, the capacity of the area may be almost indefinitely extended.



View of Timed Alarm Devices Which Transfer Grounded Lines and Incompletely Dialed Calls to a Monitoring Desk after a Lapse of Thirty Seconds. The device also gives a visual indication of the time a circuit is held.

The first problem the Administration had to solve was the selection of suitable office prefixes for the entire automatic area, such that no first three letters of any office prefix would be numerically the same as the first three letters of any other office prefix. This was settled as illustrated in the plan for the Paris telephone area.

The lettering and numbering of the Paris dial are very similar to the lettering and numbering of the New York dial. The Paris dial is shown on page 142 of the January, 1928, issue of Electrical Communication and the New York dial on page 91 of the October, 1925, issue.

A fundamental requirement of the Administration was that the system had to be flexible and capable of meeting any reasonable distribution of subscribers' lines and junctions. To meet these requirements the register circuit was designed to permit, among other things, the following:

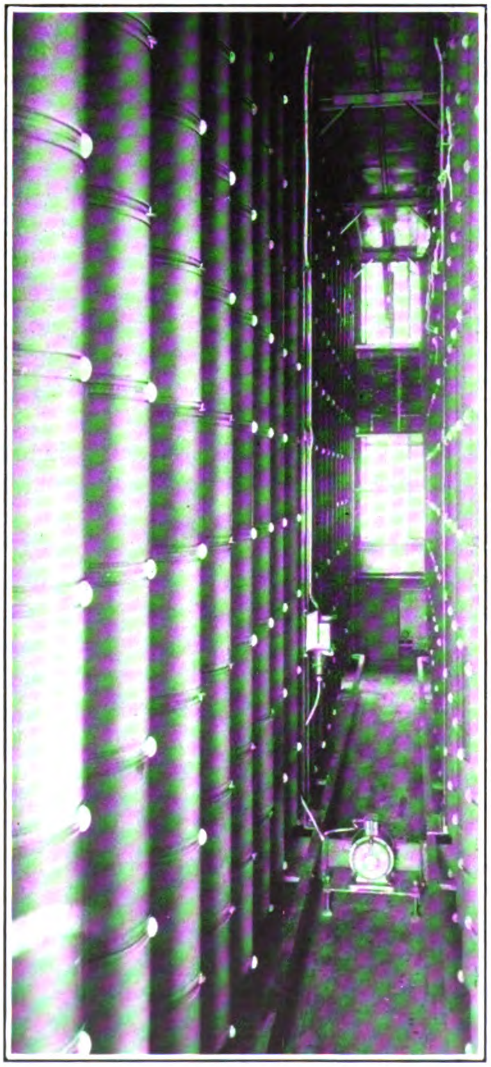
1. An office name may be changed without changing the position assigned to the office in the translator switch. That is, there is no numerical connection between the letters in the office prefix and the position occupied in the translator switch as is usual in systems arranged for office prefix translation.
2. Calls may be completed by direct junctions or passed through one to three tandem offices or selectors.
3. Multiple metering is provided for. By suitably cross-connecting the various positions in the translator switches, calls to the various offices, city and suburban, may be automatically metered one, two or four times, depending upon the rates prescribed.
4. Calls to the special services such as information, recording, etc., are automatically not metered, but the answering operator can meter such calls when necessary by depressing a key.

The present and temporary method of trunking to and from Carnot has been briefly described. The permanent trunking plan is as follows:

Calls from the automatic offices to the manual offices which will remain for some years, will be handled by call indicator positions to be installed shortly in the manual offices.

Calls from automatic offices to those manual offices which will be replaced within the next two or three years, will continue to be handled by the temporary tandem call indicator positions located in the automatic office.

Direct trunking was chosen as the means for establishing connections outgoing from the permanent manual offices to the automatic offices. Order wire trunking, even after many years of continued effort, has not proved entirely successful. Even in America, where a few years ago order wire trunking was universal, it has been replaced to quite a large extent by the so-called "straightforward trunking" system in which the request is passed over the trunk instead of over an order wire. Order wire trunking is costly, slow, and the cause of many errors, prominent among which are double connections and wrong numbers. It requires a high degree of team work, which it is difficult to realise and to maintain, between operators in different offices. The direct trunking plan for Paris is briefly described in the article[2] by Monsieur Pocholle. The equipment of the *A* positions is extremely simple. Each position receives a ten button key set which is in no way associated with the manual cord circuits and a few individual jacks for each office. These jacks are connected to the arcs of finders attached to the outgoing junctions to the automatic offices.



Rear View of Selector and Finder Bays Showing the Manner of Protecting the Rear of All Bays by Sheet Iron Covers, Thereby Guarding the Cable and Wiring Against Mechanical Injury, Dust, etc. The covers also serve to localize any fire which may start in the cabling and wiring.

An operator, upon receiving a request for a subscriber to an automatic office, inserts the calling plug into an idle junction jack assigned to that office. A double connection is impossible as the jack is not multipled on any other position. The operator completes the connection by depressing one after the other the four key buttons corresponding to the wanted number. She cannot depress the keys too quickly providing she depresses each key fully and then allows it to return fully.

Direct trunking equipment of this type was installed by the Bell Telephone Manufacturing Company for the Swiss Government in Bâle, a description[3] of which, by Mr. E. Fry, appears in *Technische Mitteilungen*, the official publication of the Swiss Telegraphs and Telephones. According to this article, *A* operators receiving from the public calls automatically distributed to idle plugs, trunk from 53 percent of the originating calls and complete the remainder in the multiple field before them. The average answering time is 2.34 seconds and the average load per operator during the busy hour is 425 calls. These figures are far beyond anything possible with order wire trunking, and it is expected that the installation of direct trunking equipment on the *A* positions in Paris will not only improve the service but will also save the Administration many millions of francs a year in operators' salaries.

The temporary semi-B positions in the auto-

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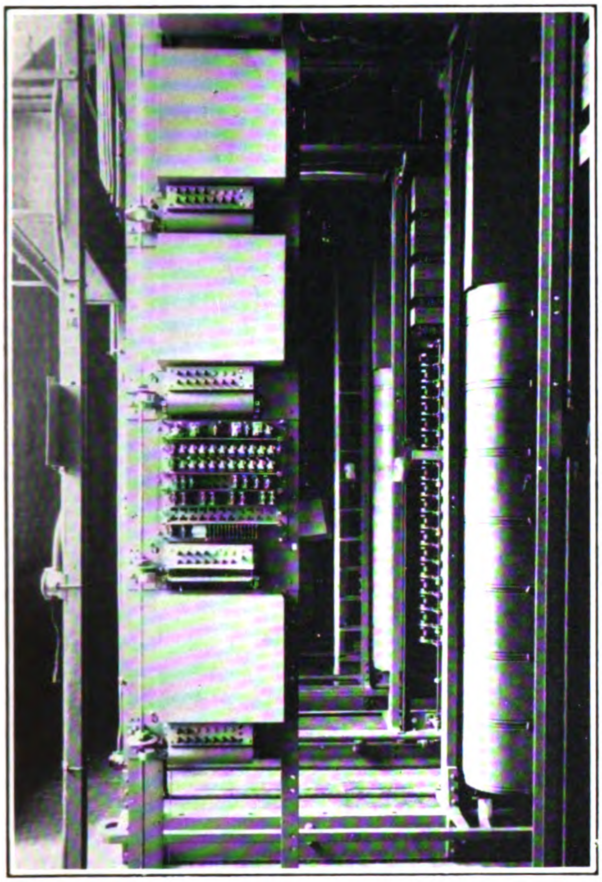
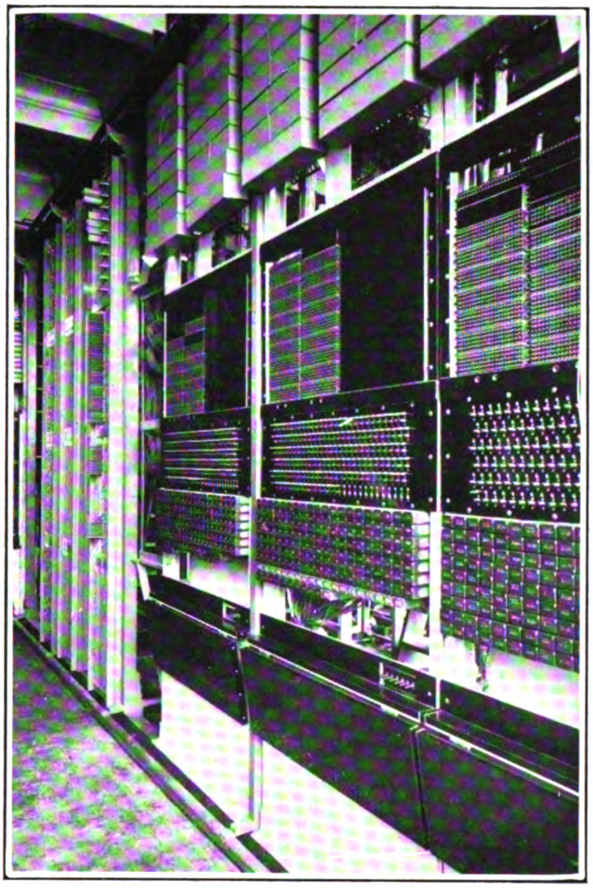
[2] Loc. cit.

[3] "Les centrales téléphoniques locales de Bâle," *Technische Mitteilungen*, Issues 2 and 3, 1928.



One of the Routine Test Bays with Equipment in Position for Four Final Selector Routine Test Circuits.



Front View of Three Automatic Traffic Recording Positions. The single conductor jacks for the second, third and fourth selectors are shown above. Next are the single conductor plugs and associated keys and near the bottom the service meters. At the extreme left are shown two monitoring and service observation positions.

matic offices will be retained for the next two or three years to handle calls incoming from the temporary manual offices.

During the ten or twelve years that it will take to eliminate manual offices from Paris and suburban areas, automatic offices will be installed at random in both areas.

Calls between an automatic office in the suburban area and an automatic office in Paris will be completed in exactly the same manner as a call between two Paris offices, the only difference being that a successful connection will be metered twice instead of once. Calls from one automatic office in the suburban area to another automatic office in the suburban area will also be completed automatically in the usual way. The charge here, however, may involve one, two, or four operations of the meter, depending upon the distance. The routing of the junctions may be made in the most convenient and direct manner.

During this transition period the suburban area will be divided into four districts as indicated on the plan for the Paris telephone area, each district being reached from the city or vice versa through a tandem centre indicated by small black squares. These tandem centres are now in course of construction and will be in operation the early part of next year. A Paris automatic subscriber desiring a connection with a manual suburban subscriber will dial the full number listed in the directory. The number will appear upon a number indicator before the proper tandem call indicator operator. The operator will complete the call manually. When the calling party hangs up after a successful connection, his meter will automatically operate twice. It will be seen that as far as the Paris automatic subscriber is concerned, the method of calling a subscriber in the suburban area is the same, whether that subscriber is connected to a manual office or to an automatic office.

Incoming calls from a suburban area to Paris will go into the same tandem office but on positions equipped for direct trunking to the desired automatic office or to call indicator positions in the manual offices so equipped.

Two number short haul toll calls require no special comment. The subscriber dials the proper special service two-digit number and arrives at the short haul toll board. The wanted party is obtained manually and a ticket is made out for the call.

For long distance calls, a manual switching section is provided, so that the completion of long distance calls is the same as in a manual office.

There are no party lines in Paris, only main and P.B.X. lines, and multiple metering requires that each line shall have a service meter.

As lines without toll deposits are refused long distance service, sections of the equipment are arranged to send calls for recording from such lines to special operators.

Acknowledgment

In conclusion, the author wishes to acknowledge the whole-hearted cooperation received, first, from the engineers of the French Telephone Administration and, later on, from all branches of that Administration. The rapid completion of plans and the subsequent rapid execution of the work could not have been achieved had not the Administration shown, in the most conclusive way, its real desire to be helpful. It has been a great pleasure to all who have been personally involved in this project, to have been able to have worked under such satisfactory conditions.

Sloane Exchange, London

By R. W. FRASER

Engineering Department, Standard Telephones and Cables, Ltd.

Introduction

WITH the introduction of the new automatic exchange at Sloane, another important stage in the conversion to automatic working of the London telephone area was completed. Cutover was successfully accomplished at midnight on Saturday, July 28, 1928, when 5,100 lines were transferred to the automatic equipment.

When the British Post Office decided to adopt for London that particular modification of the Step-by-Step system which provided the translation facilities which are so valuable in a great metropolitan area, a large amount of development work remained to be done before the system could satisfactorily meet the requirements which are considered essential by the British Post Office for good public service, and the operating conditions standardised and specified by the Post Office Engineers. This development was undertaken by the various manufacturers in conjunction with the Post Office Engineers. The Sloane equipment, installed to the specification of the British Post Office, is typical of the Step-by-Step Register-Translator system adopted for the service of the largest cities of Great Britain. Similar equipments are being installed by Standard Telephones and Cables, Ltd., at other exchanges in the London area including Bermondsey, Temple Bar, Langham and Fulham.

The new Sloane exchange which has an initial capacity of 8,400 lines, is located in a new building in Sedding Street, off Sloane Square. On the ground floor of this building, a temporary manual exchange of about 4,000 lines is accommodated. On the introduction of the automatic exchange it was planned to transfer these 4,000 lines together with other lines, which are at present accommodated in adjacent manual exchanges, to the new automatic exchange.

Trunking Scheme

The trunking scheme of Sloane Exchange showing the routing of local, outgoing, and incoming traffic is given in Figure 1. The numbers showing switch quantities on this diagram give some indication of the amount of equipment involved.

The fundamental trunking plan is the same as in other register systems in that the calling subscriber does not have direct control of the setting up of all the switches involved in a call, the dialed impulses being first received by the register apparatus (*A* digit selector and register-translator) and the call being then routed through the switching plant by trains of impulses sent out from that apparatus. In the London area a 7-digit dialing scheme has been adopted, the digits comprising the first three letters of the called exchange name and four numerals. The register equipment is designed to translate the first three digits into any other digits up to six in number according to the desired routing of the call. The four numerical digits are of course sent out unchanged since these operate the numerical and final selectors in the case of a call to the local or another automatic exchange and are displayed at a call-indicator *B* position in the case of a call to a manual exchange.

The arrangement of letters and figures on the dial is shown in Figure 2.

When a subscriber lifts his receiver to originate a call the line switch associated with his line is energised and hunts for a free first code selector. The *A* digit selector finder associated with this switch is then energised and connects the calling line to a free *A* digit selector from which dial tone is received. In response to the first or *A* digit dialed by the subscriber, this selector steps to the level corresponding to the numerical equivalent of the digit and hunts, in the same way as a group selector, for a free register-translator in the group associated with that digit. The second and third (or *B* and *C*) digits and the four numerical digits are received by the register-translator.

When the *B* and *C* digits have been received, the register-translator commences to send out the translated digits over a path which has been established through the *A* digit selector and

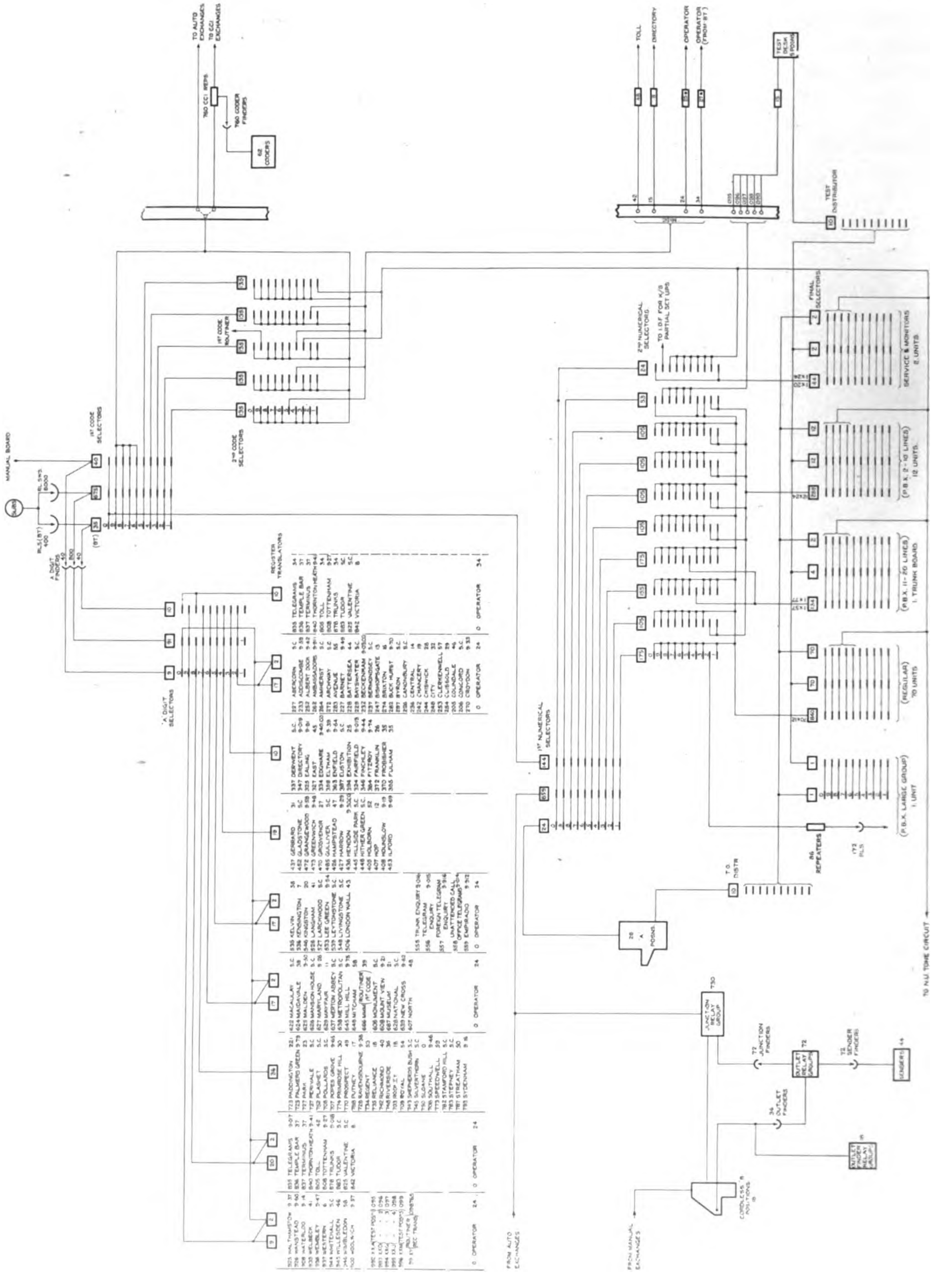


Figure 1—Switching Scheme. Sloane Exchange.

finder to the first code selector which receives the first translated code digit. This path is then extended step by step through the switching equipment, according to the digits sent out by the register-translator. When the last numerical digit has been sent out, the *A* digit selector and register-translator clear down and the calling line is switched through at the first code selector to the talking circuit which has been built up through the subsequent switches.

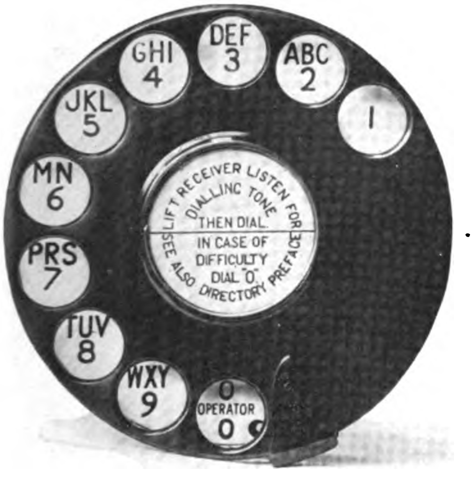

GHI
4
DEF
3
ABC
2
1
JKL
5
MN
6
PRS
7
TUV
8
WXY
9
0
OPERATOR
0
LIFT RECEIVER LISTEN FOR DIALLING TONE
THEN DIAL
IN CASE OF DIFFICULTY DIAL "0"
SEE ALSO DIRECTORY PREFACE

Figure 2—Dial.

In Figure 1, the names of London exchanges are grouped according to the *A* digit selector level from which they are reached. In order to avoid difficulties due to faulty preliminary impulses, the arrangement of the letters in the dial is such that the *A* digit is never 1, and the *A* digit selector is designed to release and restore to normal should it be stepped up to the first level by a preliminary impulse.

Level 0 of *A* digit selectors gives access to a group of special register-translators which must operate as soon as they are seized by a subscriber dialing 0. These register-translators are also made accessible from one of the later choices of other *A* digit selector levels. This is indicated in Figure 1 where the 10 zero-level register-translators are shown distributed between levels 2, 5, 6, 7 and 9. When reached via a level other than the 0 level, the zero register-translator operates as a regular switch. This is effected by means of a shunt-field relay in the register-translator, one winding of which is normally energised from the first code selector in the direction which prevents the operation of the relay. Between level 0 of *A* digit selectors and the register-translators reached from that level, the two lines are crossed so that the shunt-field relay operates as soon as the *A* digit selector cuts through.

In the list of exchange names shown in Figure 1, the numerical equivalent of the first three letters of each name is shown at the left and the translated code digits indicating the routing of traffic to that exchange are shown to the right of the name. Local traffic is routed direct to first numerical selectors from level 0 of first code selectors, the code translation for SLOane being 0. Traffic to a number of exchanges whose community of interest with Sloane is small, or which are too far from Sloane to warrant direct junctions, is routed in one block via level 9 of first code selectors to the Tandem exchange; the remaining digits of the translations operate on the selectors at Tandem to route the call to the particular exchange required.

The traffic to the three exchanges, Western, Kensington, and Victoria, is of such volume as to warrant its being trunked direct from first code selectors, and levels 6, 7, and 8 respectively are, therefore, allotted to these exchanges. The remaining five first code selector levels give access to five groups of second code selectors, each group carrying the traffic to a number of exchanges. The allocation of second selector levels to particular exchanges is indicated in the list of translations.

A subscriber wishing to make a trunk call dials the digits TRU. The translated digits 902 route the call through Tandem and connect his line to a recording position at the Trunk exchange. The final trunk connection which involves the re-call of the calling subscriber, is established via the cordless *B* board mentioned later in connection with incoming traffic from manual exchanges.

A call to any exchange reached through the London Toll exchange is made by dialing TOL. These digits are translated to 42, establishing a connection between the calling line and the Toll exchange switchboard. The Toll operator obtains particulars of the call from the subscriber and completes the connection to the called exchange.

Similarly the digits TEL are dialed when it is desired to reach an operator in the Phonograms

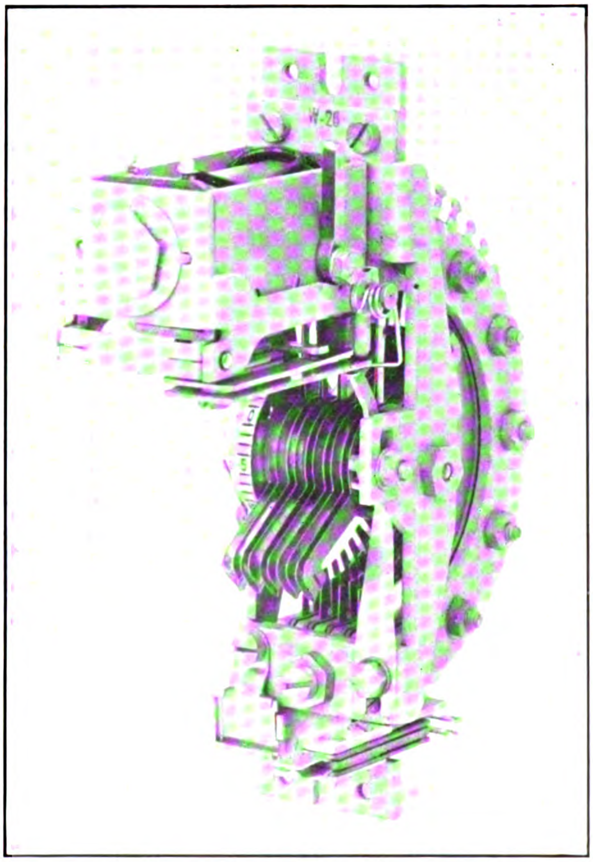


Figure 3—Subscriber's Line Switch.

Office for the transmission of a telegram by telephone and the digits DIR when any Directory service is required.

For any special services such as Enquiries, Assistance, or Information, the subscriber dials 0. This digit is received by the *A* digit selector and gives access to one of the special group of register-translators reached from the tenth level. As soon as one of these register-translators is taken from level 0 it commences sending out the translation 24, which routes the call over one of a group of lines terminating in calling equipment associated with answering jacks at the manual *A* board.

Subscribers who for any reason do not wish to have trunk service given on their lines, are connected to special groups of first code and *A* digit selectors. From levels 0 and 8 of these *A* digit selectors, access is given to a special group of register-translators which have a common translation for 0, TRU, TOL and TEL, this translation being different from those given for the corresponding calls from other subscribers. Thus a "barred trunks" subscriber calling Trunk, Toll or Telegrams, or dialing 0 for assistance, is connected via a special group of lines to an operator who deals with all such calls from these subscribers.

The call indicator method adopted by the British Post Office, for handling traffic from automatic to manual exchanges in the London area, differs from methods previously used, in that a call instead of being stored in the manual office if the operator is not ready to deal with it

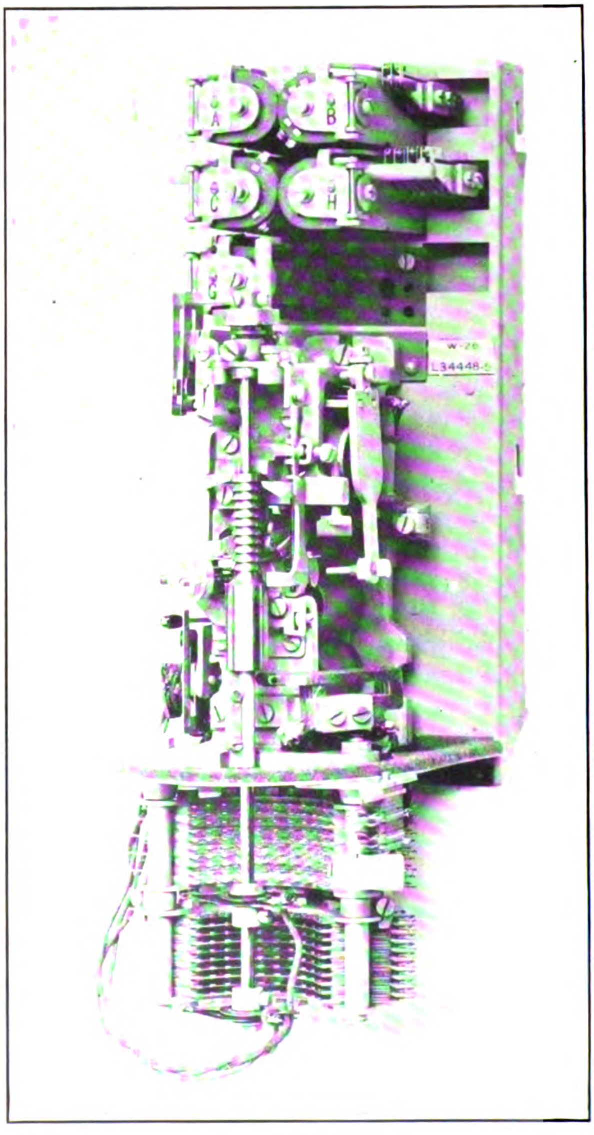


Figure 4—Group Selector.

at once, is held in the automatic exchange. This necessitates a scheme for transferring the call rapidly over the junction as soon as the position becomes free to receive the call, and has resulted in the development of the "code system," in which the call is first routed by the register-translator to a coder in the local exchange, the coder being temporarily associated with the outgoing junction by means of a repeater and coder finder. The coder receives and stores the four numerical digits and allows the register-translator to clear down in the same way as in a call to an automatic exchange. When the manual end is ready, the four digits are transferred over the junction, not as a series of step-by-step impulses, but as a code of short impulses of different polarity and strength. These impulses are received and decoded by special apparatus at the manual end, the four digits being ultimately displayed at the call indicator position. As soon as the coder is discharged it clears down and the coder call indicator repeater switches the connection through from the last code selector level to the outgoing junction.

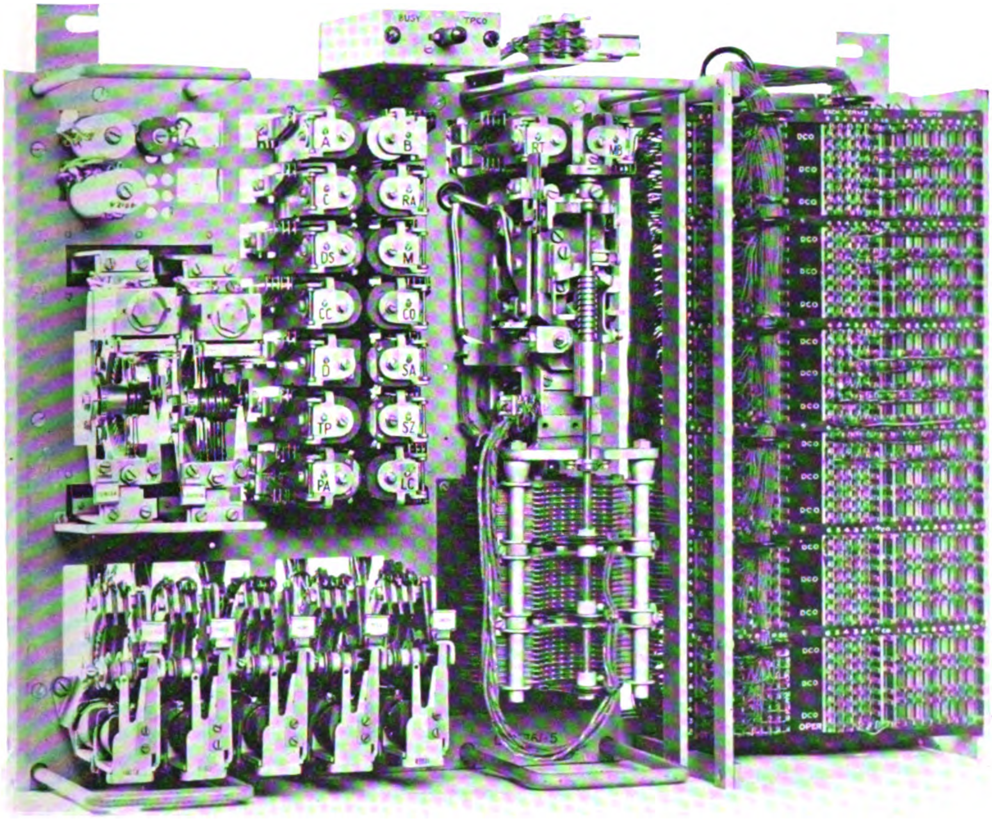


Figure 5—Register-Translator.

Incoming traffic from manual exchanges, including that from Trunk and Toll is handled on an order wire basis at a group of cordless *B* positions. Each incoming junction terminates in a junction relay group giving access to a particular selector (as indicated in Figure 1) and has associated with it at the position an assignment key, a two-position key designated "order wire emergency" in one position and "disconnect" in the second position, and a junction lamp which glows when the junction is busy. The ultimate capacity per position is 50 junctions but in the initial equipment the positions are equipped for a maximum of 40.

The position key set, used in setting up the call, consists of a strip of 10 keys of the vertical

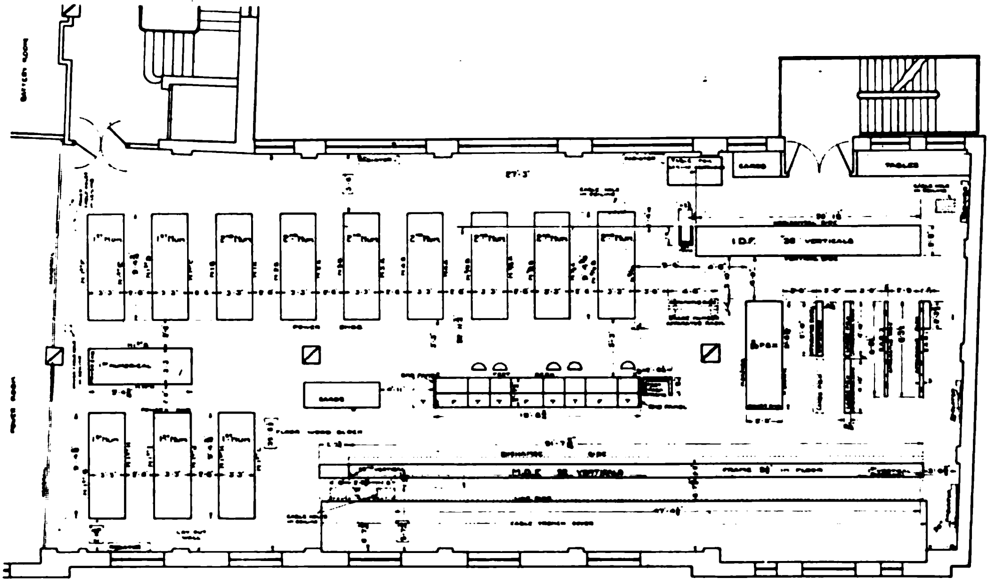


Figure 6—Floor Plan, First Floor.

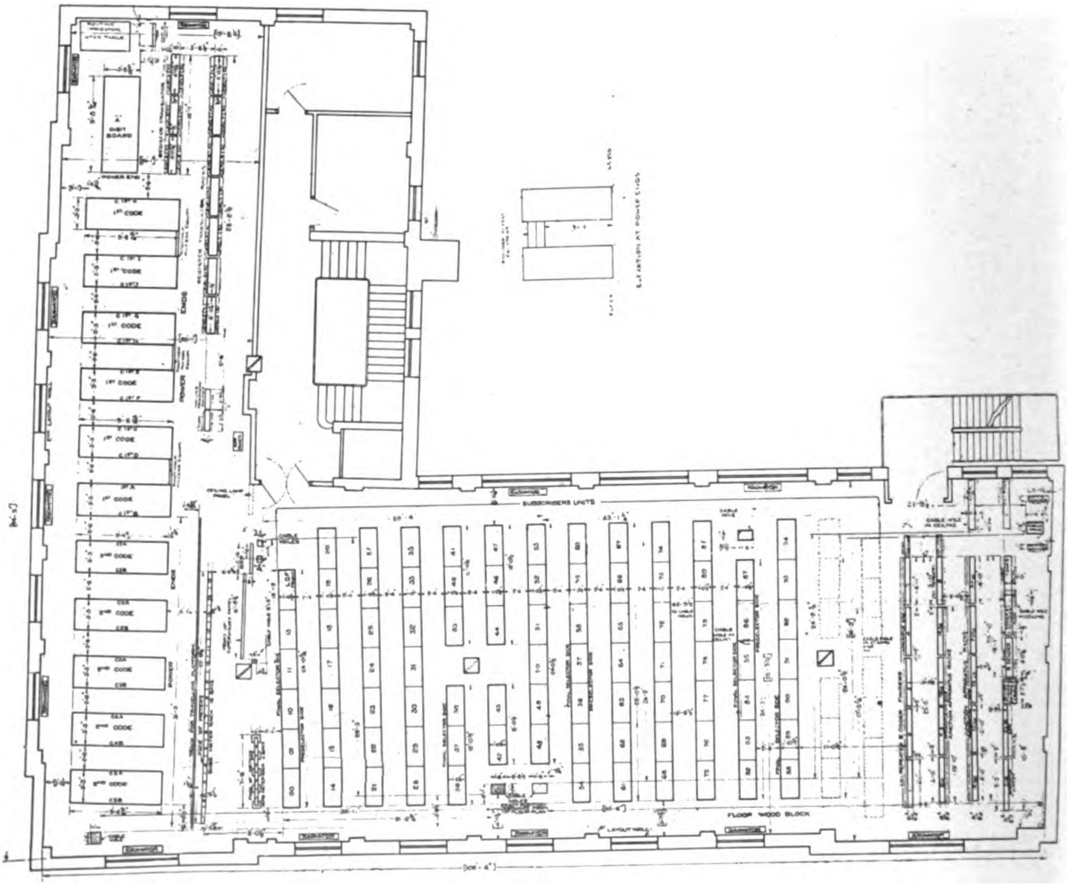


Figure 7—Floor Plan, Second Floor.

push button type numbered 1 to 9 and 0. Above these is a cancel key of the same type, by means of which the *B* operator can cancel the call, if, before completing key-sending, she realises that she has set up a wrong digit.

Two outlet finders (used on alternate days) are allotted to each position and give access to one of the four outlets allotted to a position. The change-over from one finder to the second is effected by means of a key at the position.

An outlet comprises a relay group, a sender finder and a junction finder and serves to connect the position key set to the sender, and the sender to the junction relay group and numerical selectors. Each outlet has associated with it at the position a busy key, by means of which a faulty outlet may be busied, and a lamp which glows whenever the outlet is engaged.

When a call is received on an order wire, the *B* operator allots a free junction to the *A* operator at the same time depressing the assignment key corresponding to the junction. The operation of the assignment key causes the sender finder to hunt for a free sender and the junction finder to hunt for the assigned junction relay group. When a sender is found, the digit key set is connected to it via the outlet relay group and finder and the junction lamp glows indicating to the operator that the sender is ready to receive the call. Meanwhile the *A* operator takes up the assigned junction.

Should the *A* operator take up an unassigned junction the corresponding junction lamp flickers. By operating the assignment key of this junction the *B* operator cancels the first assignment. The flicker ceases as soon as the new assignment is made and the lamp glows when a sender is found.

The four digits of the required number are set up in the sender by the successive operation of the corresponding four digit keys at the position. When the last key has been operated the outlet finder steps on to the next outlet, allowing the operator to proceed with another call while the sender automatically sends out, to the numerical

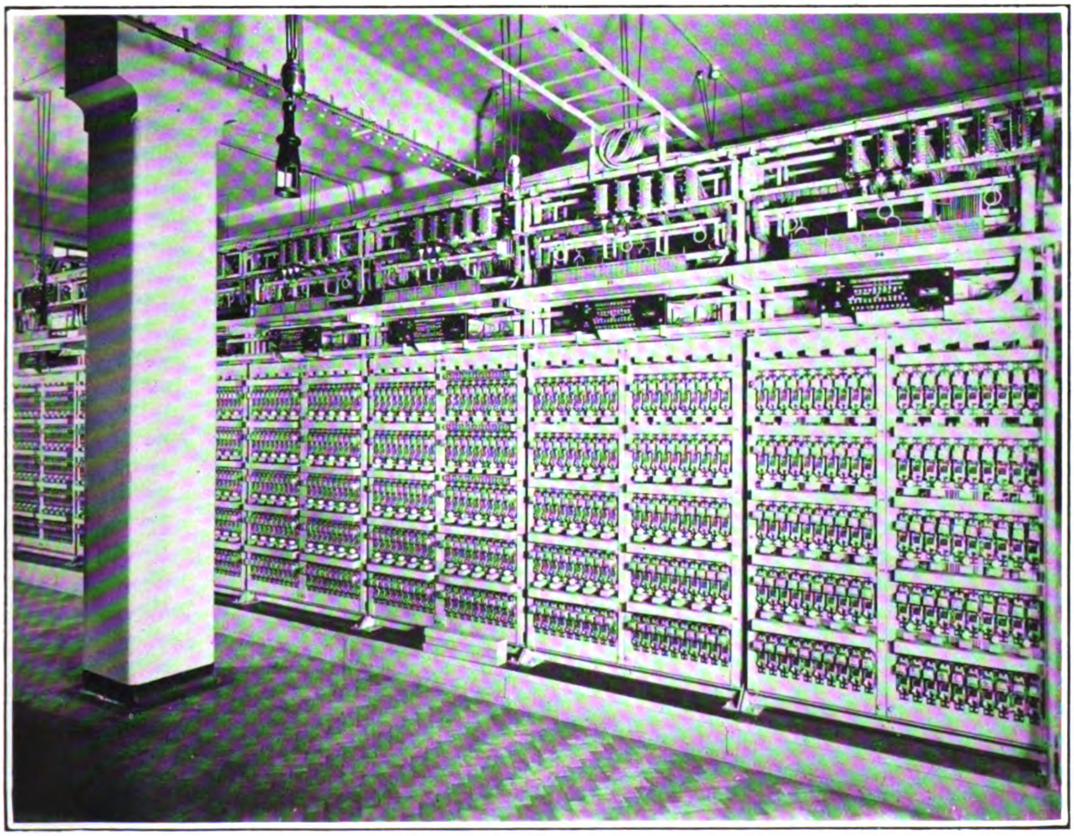


Figure 8—Suite of Line and Final Units—Line Switch Side.

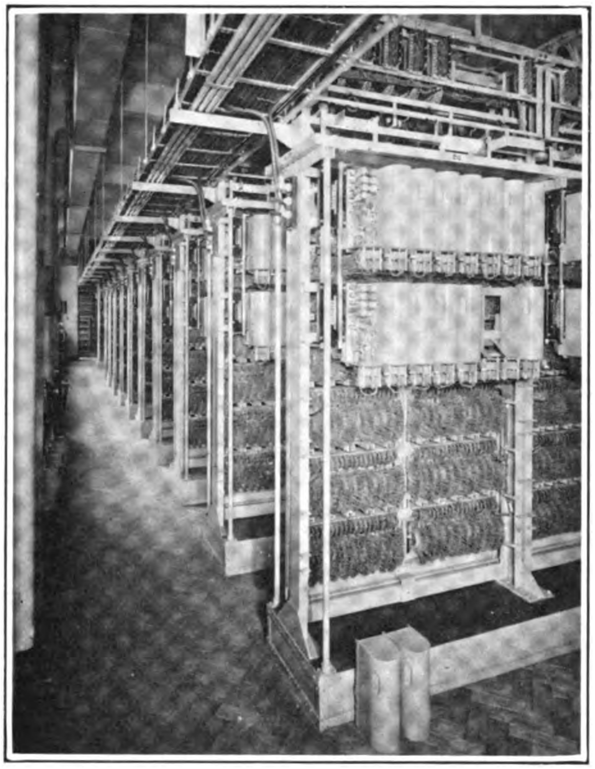


Figure 9—Line and Final Units—Final Selector Side.

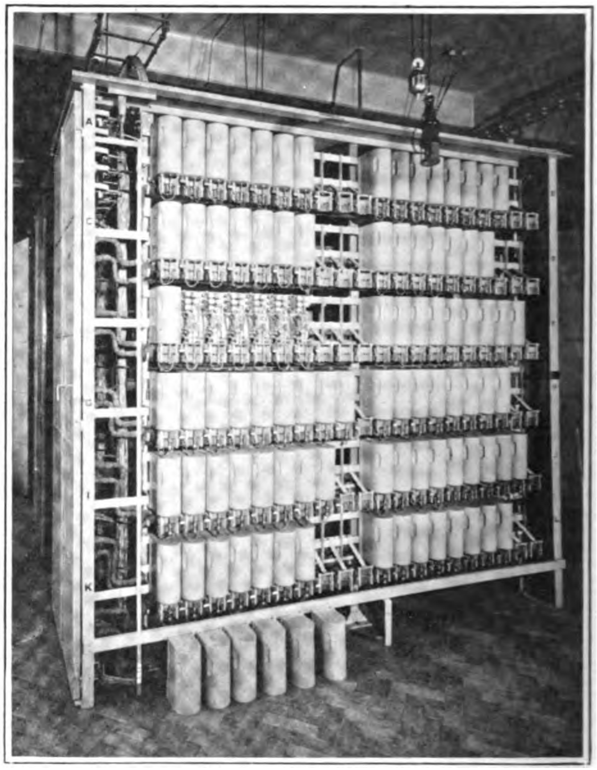


Figure 10—First Numerical Selector Board.

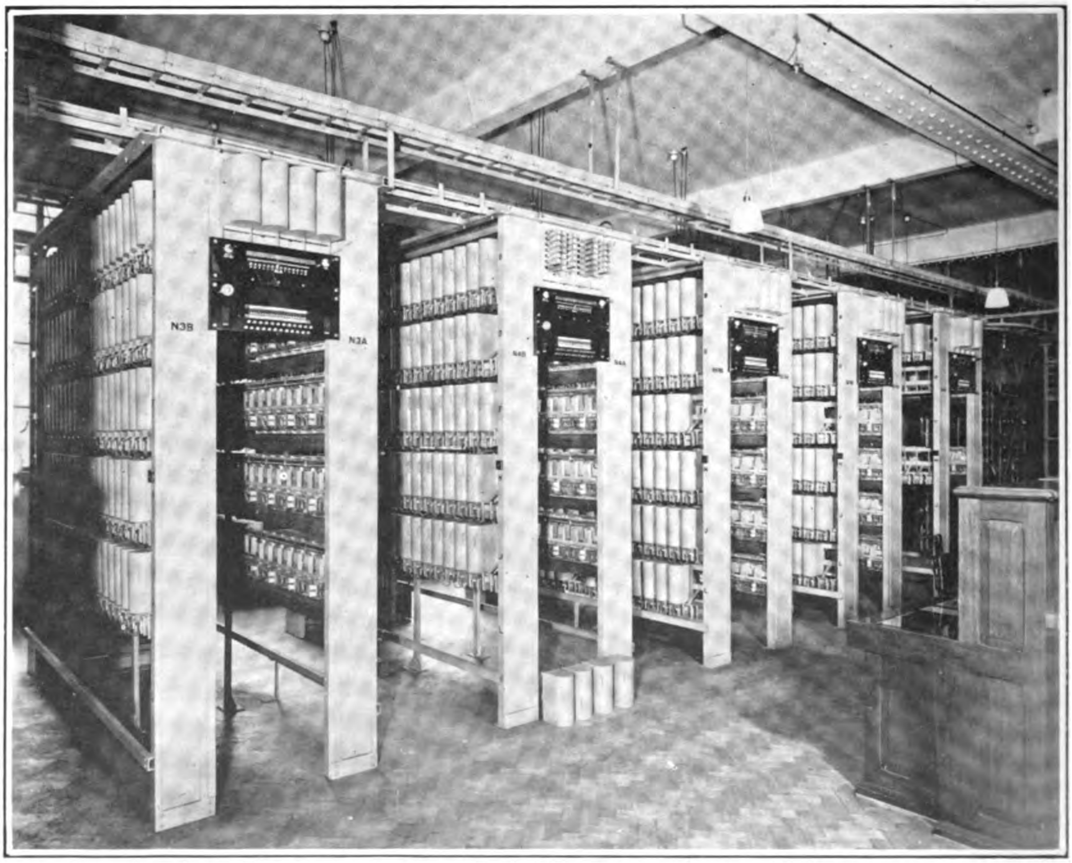


Figure 11—Second Numerical Selector Boards—Power Ends.

and final selectors, the four trains of impulses corresponding to the four digits which have been set up. When sending is complete the sender clears down and the junction relay group switches the connection through from the *B* position to the selectors, while the common apparatus is released and becomes free for another call.

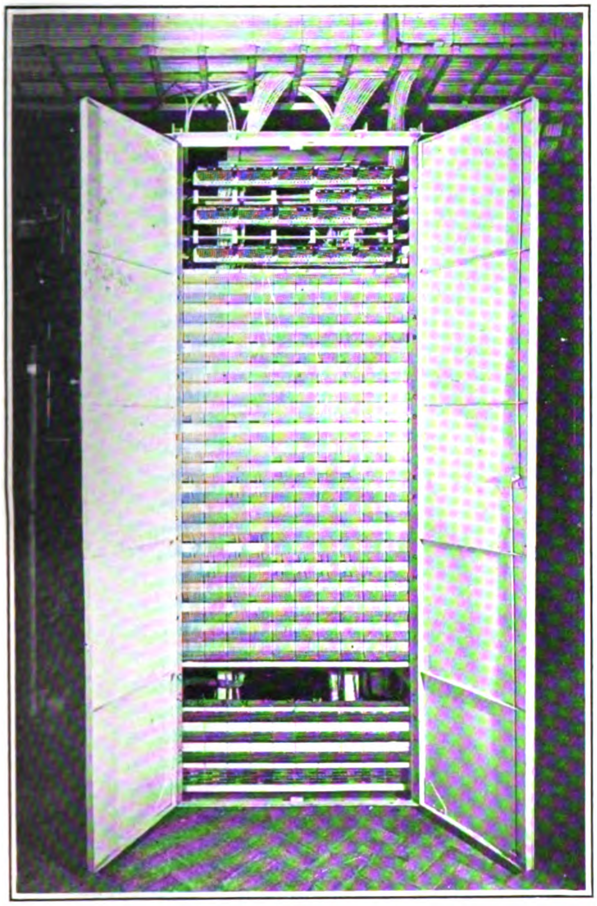


Figure 12—Grading on First Numerical Selector Board Terminal Assembly.

Supervision is left entirely to the *A* operator; the junction lamp at the *B* position is extinguished, and the apparatus set up in the automatic exchange is released when that operator withdraws the plug from the outgoing junction.

In the event of the called subscriber being engaged or of an eleventh step busy on a numerical selector, the busy signal is passed back to the *A* operator and to the calling subscriber by the automatic apparatus.

The disconnect key associated with the junction is used to disconnect, and prevent the use of, any junction if a call is not in progress. With the key in the "disconnect" position the junction lamp glows indicating that the junction is not to be used. The key is thrown when tests are being made on relays in the junction relay group, or if the junction or relay group is faulty.

A faulty order wire is disconnected by means of an order wire disconnect key at the *B* position and by throwing a junction key to the "order wire emergency" position that junction may be used as an order wire.

Since there is a transmission bridge in the first code selector as well as in the final selector there is no need for impulse repeaters on lines outgoing to automatic exchanges. The CCI repeaters in lines to manual exchanges are required for connecting the coder to the junction and provide no transmission feed when the final connection is established.

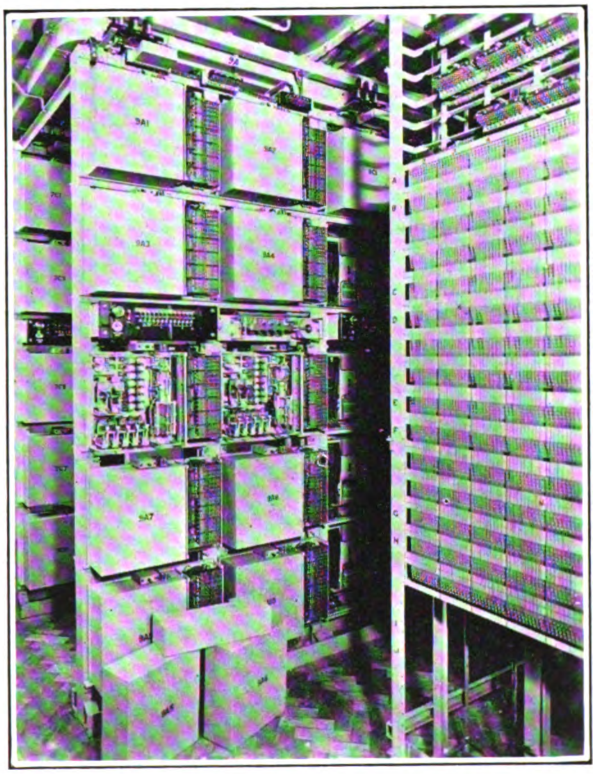


Figure 13—Register-Translator Rack and *A* Digit Selector Board Terminal Assembly.

The local switch train in a call to automatic or manual exchanges is held by the first code selector. In a call incoming from an automatic exchange, the incoming switch train is held by the final selector and in a call from a manual exchange a transmission bridge in the junction relay group is under the control of the *A* operator at the manual exchange and provides a loop forward to the final selector which holds the first and second numerical selectors over the release trunk.

The relay groups provided in the lines to special services (directory and assistance) are required to provide signaling facilities.

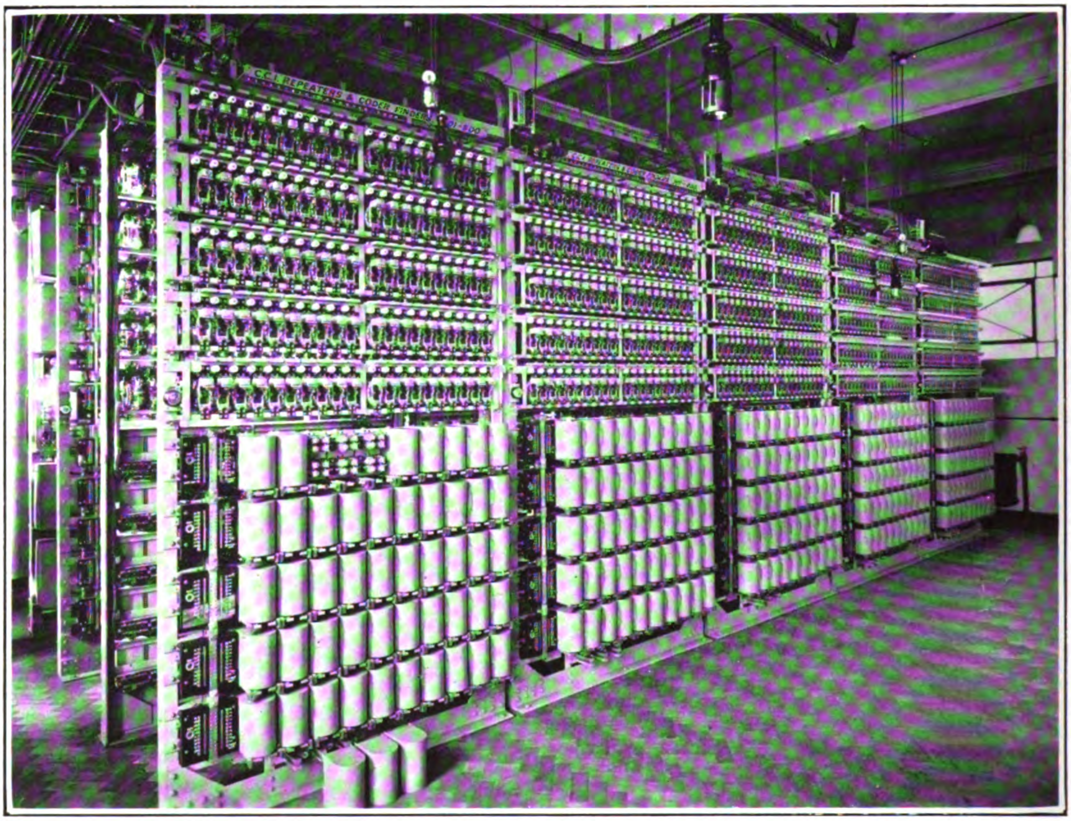


Figure 14—CCI Repeater and Coder Finder Racks.

Apparatus

In order to comply with British Post Office requirements, the register-translator system has been built up on the general type of apparatus which has become practically standard in Step-by-Step systems. Typical switches as used in the Sloane equipment are shown in Figures 3 and 4, and with the exception of the minor switches used in the register-translator, the whole of the switching plant, including the larger switch units such as register-translator, sender and coder, is built up on these two types of switches. The arrangement of apparatus in the register-translator assembly is shown in Figure 5.

The subscriber's line switch and the various finder switches indicated in the switching scheme diagram are of the type shown in Figure 3. Since the outlets from the banks of line switches, *A* digit selector finders and coder finders are graded, these switches are of the homing type, so that only 24 of the 25 points are utilised, the wipers resting in the home position on the first set of contacts. The junction finder is equipped with a double bank and two sets of single-ended wipers in the manner normally adopted to provide a 50-point switch.

All code, numerical and final selectors in the Sloane equipment, with the exception of the final selector for large P.B.X. groups, are of the type shown in Figure 4. Group selectors arranged to hunt over 20 outlets in one level are not installed, though these are being adopted in later exchanges which are being installed in the London area by Standard Telephones and Cables, Ltd.

Small P.B.X.'s with not more than 10 exchange lines are reached through final selectors which are designed to commence hunting over the P.B.X group if the first line reached by dialing is found busy. If all lines are busy, the wipers stand on the last line without being electrically connected to it, while the "busy" signal is sent back. The switch is also designed to give access to individual lines so that, if desired, both P.B.X. and individual lines may be accommodated on the same level, as long as the lines to one P.B.X. are consecutive.

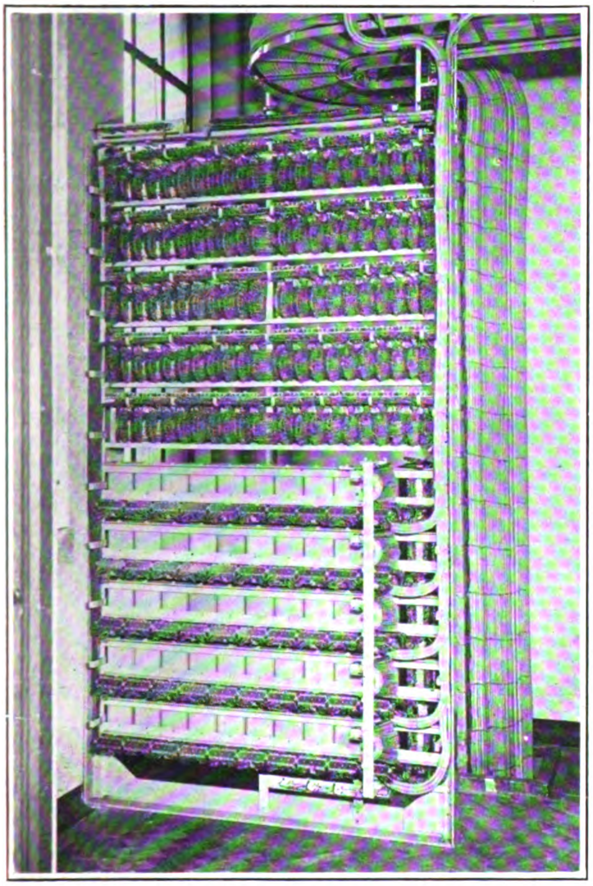


Figure 15—CCI Repeater and Coder Finder Rack—Rear View.

The 11–20 line P.B.X final selector is constructed on the lines of the 20-group selector. The P.B.X. group is reached when the tens digit of the directory number is dialed and the switch then automatically hunts over the P.B.X. group testing two lines in each position.

In the initial equipment of Sloane exchange there is only one P.B.X. having more than 20 lines. The final selector giving access to this P.B.X. consists of two 50-point rotary switches and an associated relay group. In the Sloane switching scheme the P.B.X. is reached when the hundreds digit has been dialed. Hunting is delayed until the tens digit has been received, after which one of the switches commences to hunt over 49 lines and if it fails to find a free outlet, the second switch hunts over the remaining lines in the group. If all lines are engaged, the "busy" signal is returned from the last point of the second switch. A final selector of this type gives access to a maximum of 97 lines.

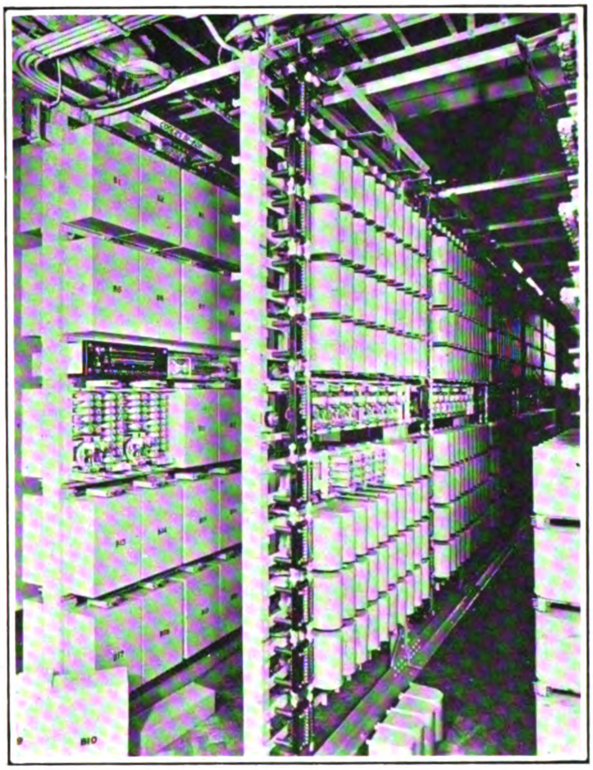


Figure 16—Coder Racks and Junction Apparatus Racks.

With the trunking arrangement used in Sloane, the large group P.B.X. takes up 100 numbers in the exchange numbering scheme. In later exchanges, where the number of large group P.B.X.'s would involve the suppression of an abnormally large number of directory numbers, an additional switching stage is introduced, the P.B.X. final selector being reached from a third numerical selector.

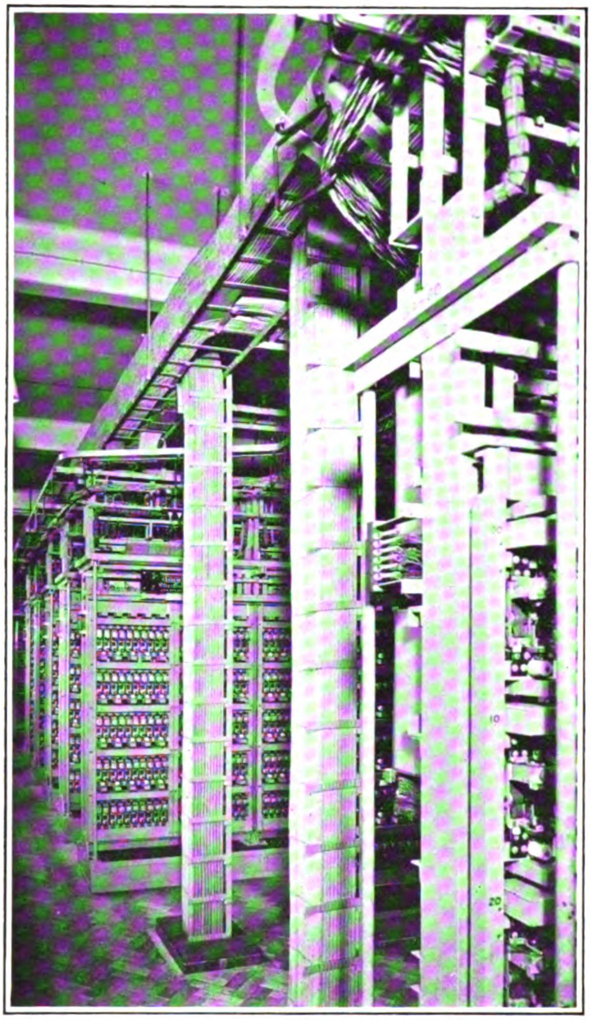


Figure 17—Cabling from MDF to Line and Final Units.

The various relay groups, such as junction relay groups, CCI repeaters, etc., are mounted one or two circuits per base on standard base plates. Figures 14 and 16 show some typical groups.

Equipment

The layout of the automatic equipment on the first and second floors is shown in Figures 6 and 7, and some typical views showing methods of mounting apparatus are given in Figures 8 to 16. Figure 8 shows the line switch side of a suite of seven line and final units, the line switches and associated line and cutoff relays being mounted 100 per unit on two gates carrying 50 each. The arrangement of the final selector side of the rack is seen in Figure 9.

Double-sided racks of the type shown in Figure 10, are used for mounting all code and group selectors, *A* digit selectors and 11–20 P.B. X. final selectors. In Figure 11 a view is given of the power ends of a number of second numerical selector boards.

The grading between selector stages is carried out on terminal assemblies located at the end of the selector boards. A typical example of this grading is shown in Figure 12. The selector banks are multipled in half shelves of 10, the multiple from the bank of each half shelf of selectors (designated A, B, C, D, etc., on each side of the board, as shown in Figure 10) is brought out to the terminal assembly, the 10 outlets from each of the 10 levels (numbered 1 to 9 and 0 in Figure 12) being arranged in one horizontal row. In the example shown in Figure 12, only 10 half shelves per side are equipped. The grading of the outlets from each level is then carried out by commoning up with lengths of bare cadmium copper wire.

Figure 13 indicates the method of mounting register-translators, 10 on each side of the rack.

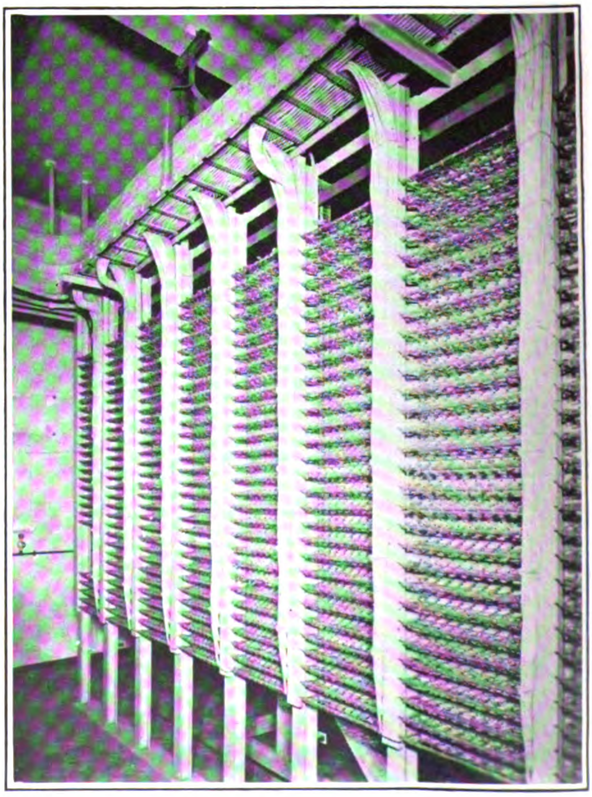


Figure 18—Subscribers' Meter Rack—Rear View.

In order to facilitate the replacement of a faulty register-translator panel, the panels are arranged to jack into position on the rack and are secured by wing nuts which are easily accessible. The impulse machine which operates the interrupter springs associated with all the register-translators on one side of the rack, jacks into position alongside the fuse panel. The machine consists of a small motor, which by means of an eccentric on its shaft, imparts a reciprocating motion to the common rod controlling the moving spring of each springset. To ensure that the impulse speed for all machines shall be the same, the motors are all driven from a common motor alternator, the speed of which is controlled within limits of ± 2 percent.

On the right of Figure 13 a portion of the terminal assembly end of the *A* digit selector board is seen, the doors being removed to show the grading between *A* digit selectors and register-translators.

Figure 14 shows a suite of 5 CCI repeater and coder finder racks. Each relay panel mounts the apparatus for two repeater circuits, the complete rack capacity consisting of 100 repeater circuits and 100 finders. A rear view of the CCI repeater rack showing wiring and routiner access equipment is given in Figure 15.

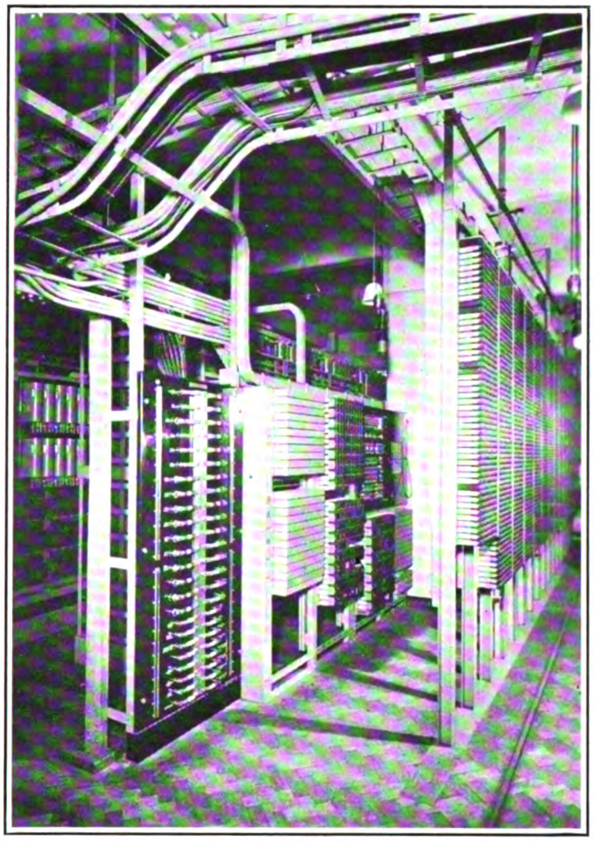


Figure 20—Distribution Fuse Panel (Second Floor), Power Supervisory Apparatus and Subscribers' Meter Rack.

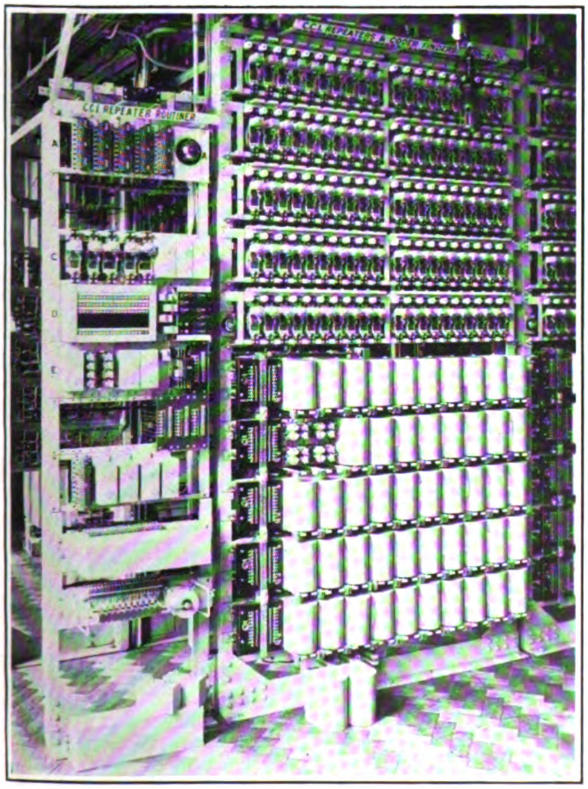


Figure 19—CCI Repeater Routiner.

The coder rack (Figure 16) is of the same type as the register-translator rack. Two coders are mounted as one unit which jacks into position on the rack and the complete rack equipment consists of 40 coders. One impulse machine, with motor, is mounted on each side of the rack.

Figure 16 also shows a suite of junction apparatus racks. Each rack is designed to carry the junction relay groups for two cordless *B* positions, the present equipment being 80 circuits and the ultimate capacity 100. This rack also mounts the 8 junction finders associated with the two positions. Outlet racks each designed to carry the equipment for ten positions are used to mount the remainder of the outlet apparatus.

Two typical cabling views are given in Figures 17 and 18. The former shows the cabling from the M.D.F. on the first floor to the line and final units on the second floor. The other shows the cabling at the rear of the subscribers' meter rack.

Maintenance and Testing

The maintenance and routine testing of a large register-translator installation constitutes a formidable task. This has, however, been simplified by the introduction of automatic routiner equipment which is being specified by the British Post Office for all such exchanges.

This equipment is designed to carry out a series of routine tests on each of a particular group of circuits, the tests proceeding from circuit to circuit automatically, until the whole group has been tested or until a fault is found. The nature of the particular fault is indicated by one of a series of lamps. These automatic routiners are provided for register-translators, first code selectors, CCI repeaters, coders, junction relay groups, senders, 11–20 and 21–97 P.B.X. final

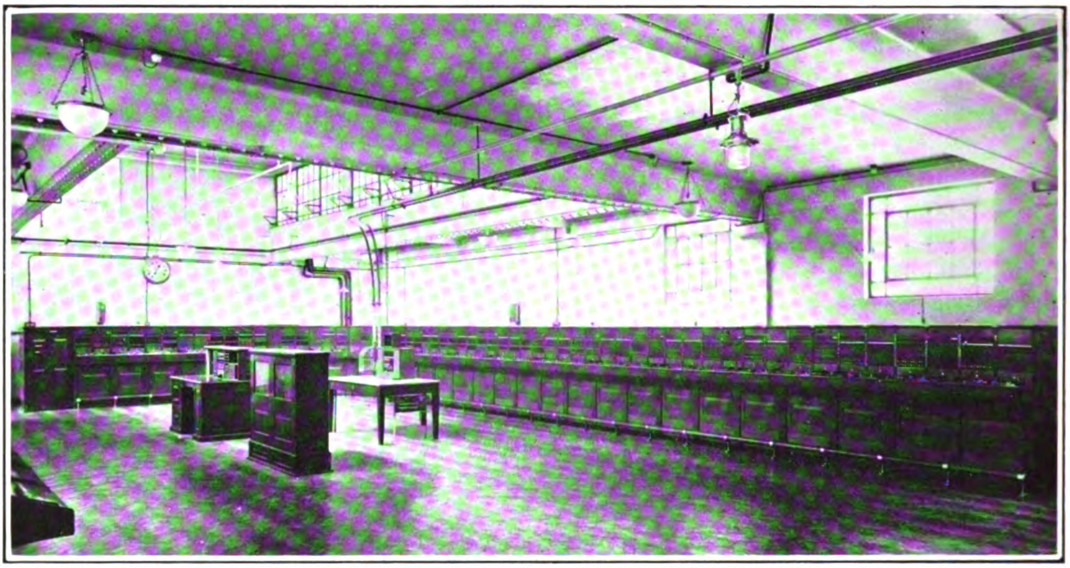


Figure 21—Manual Operating Room—*A* Positions.

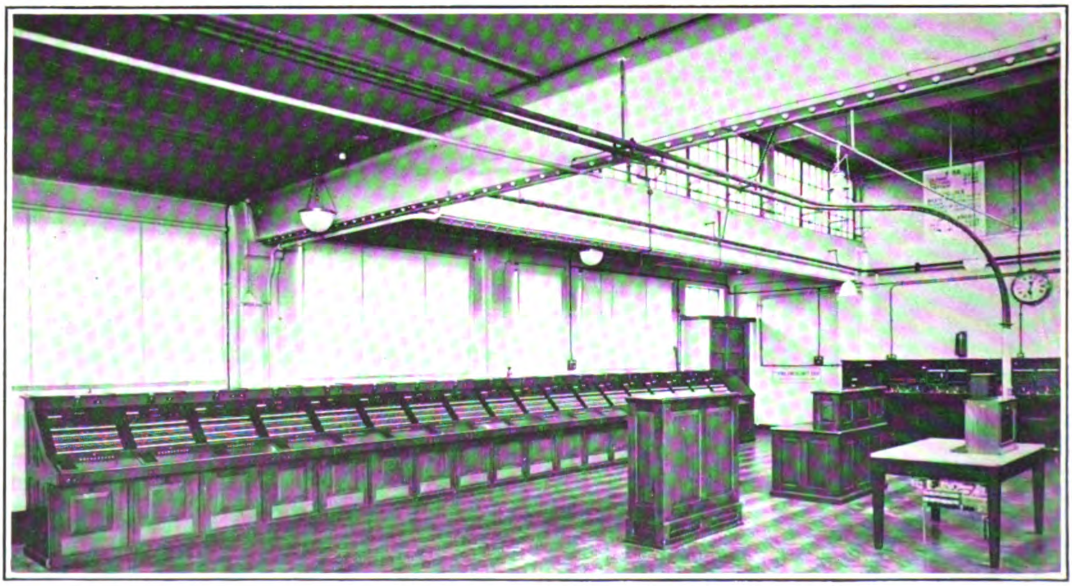


Figure 22—Manual Operating Room—Cordless *B* Positions.

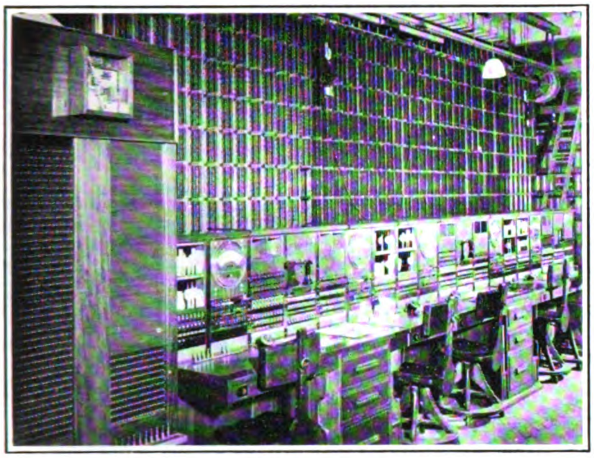


Figure 23—Test Desk and MDF.

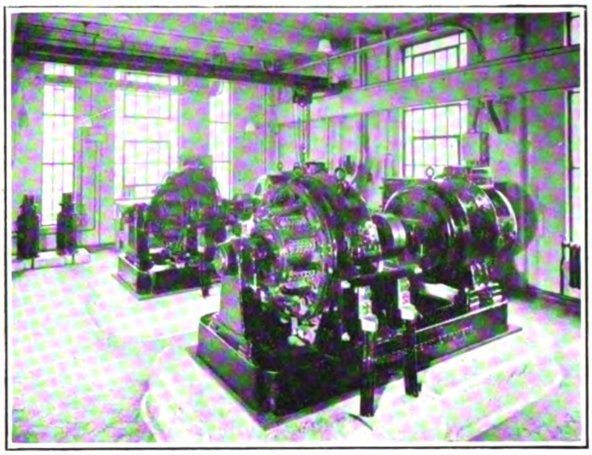


Figure 24—Machines.

selectors. The CCI repeater routiner is shown in Figure 19. To connect the routiners to the apparatus under test, access equipment is provided at the apparatus racks. The routiner access equipment for CCI repeaters is shown in Figure 15. This method of mounting the access equipment will only be used at Sloane, where the routiner equipment was ordered after installation of automatic equipment had commenced.

The common supervisory and alarm apparatus for the automatic and power equipment, including time alarm relays used on delayed alarm circuits and ceiling lamp relays, is mounted on the supervisory panel, shown in Figure 20. The supervisory apparatus particular to a unit is mounted at the unit. In the case of the selector board, for example, this apparatus is mounted above the fuse panel, as shown on Figure 11. The supervisory scheme provides for an alarm being given in the apparatus room by a ceiling lamp and a bell during the day; at night the alarm is extended to the manual board, rings a night alarm bell and lights an urgent or non-urgent supervisory lamp according to the nature of the fault.

The fuse panel on the third bay of the supervisory panel mounts the fuses for supervisory apparatus, ringing, ringing return, and busy tone circuits and circuits distributing 3-phase current to the interrupter motors on register-translator, sender and coder racks.

On the upper part of the fourth bay is mounted a fault localisation jack panel, associated with the busy and N.U. tone circuits. The busy tone lead to each line and final unit and to each side of a selector board passes through a break jack on this panel. Should a partial earth fault occur in any of the tone distribution leads, the fault may be localised by plugging a telephone set into the listening jack beside the jack panel, and listening to the tone received through each jack, when tested by the plug and cord seen in the photograph. The effect of a partial earth fault on any lead is to weaken the tone on all leads. When the listening plug is inserted in the jack associated with the faulty lead, the fault is cut off and the normal tone is heard, while in all other jacks a weak tone is heard. To facilitate testing, a group test is provided by means of a number of master jacks, so that a group of leads including the faulty lead may first be located, and then the actual lead found by testing the individual jacks in the group.

Manual Board Equipment

The *A* board in Sloane exchange (Figure 21) consists of a suite of twenty-eight positions including one service P.B.X. position, two supervisors' positions and twenty-five positions for assistance, interception and coin box service. The switchboard sections are similar to those of the standard No. 10 board but have no subscribers' multiple.

A group of twenty-four circuits to first numerical selectors is multipled over the *A* board, for completing local connections, and a similar group of 30 lines to first code selectors is provided for outgoing calls requiring the use of a register-translator.

The cordless *B* suite (Figure 22) consists of eighteen positions. The main features of these positions have been described in connection with the method of handling traffic from manual exchanges.

The 5-position test desk is shown in Figure 23 with the test jack frame, used for testing outgoing junctions, mounted alongside. Each outgoing junction passes to the M.D.F. via one of the jacks on this frame. By means of a circuit which terminates in a plug at the test jack frame and in a multiple jack at the test desk, any junction can be extended to the desk for testing purposes. The pendulum of the dial speed tester is mounted on the panel above the test jack frame.

Power Equipment

The capacity of the power plant of a register-translator exchange, such as Sloane, is necessarily much greater than is commonly provided in telephone exchanges, since it is estimated that the peak load reached during the busy hour will be of the order of 1,200 amperes.

The two charging sets shown in Figure 24 have each an output of 1,200 amperes at 57 volts, with regulation between 50 and 68 volts. Generators of the telephone type are used so that, if required, they may carry part of the load during busy periods. The motors are 400 volt shunt wound D.C. machines designed to run at a speed of 600 r.p.m.

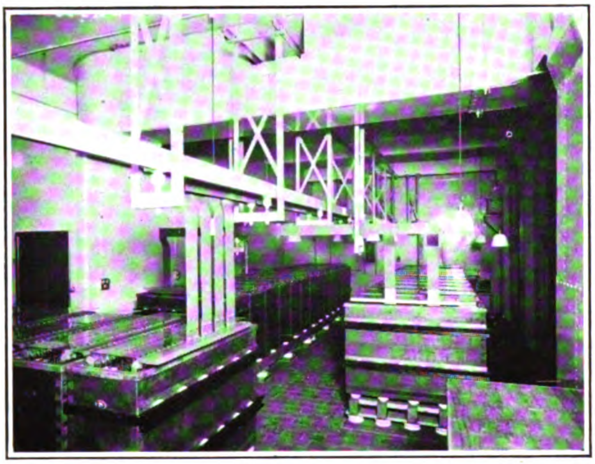


Figure 25—Battery Room.

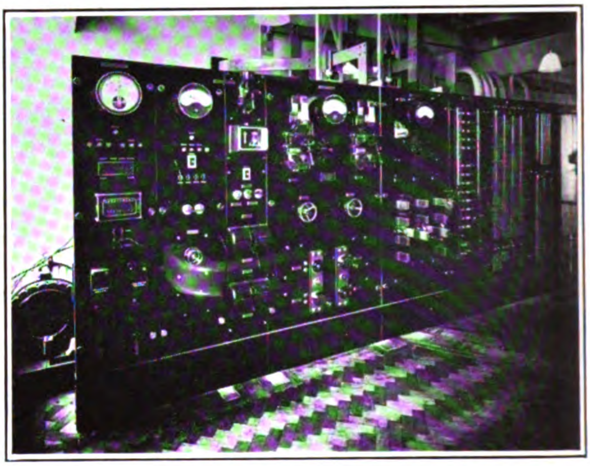


Figure 26—Power Board, D.F.P. (First Floor) and Manual Fuse Panel.

The two motor-alternators, controlling the interrupter motors for register-translators, senders and coders, are seen in the background of Figure 24. The two sets are driven from the 50 volt battery supply and each supplies alternating current at a frequency of 40 cycles for coders and 20 cycles for register-translators and senders. Provision is made for automatically switching in either set in the event of a failure in the supply from the other set.

The two 25-cell batteries have each an ultimate capacity of 7,496 ampere-hours at a 9 hour rate and are equipped initially with plates for an output of 6,460 ampere-hours. One counter-E.M.F. battery of 7 cells is provided for P.B.X. power supply. A view in the battery room is given in Figure 25.

The main discharge circuits are connected to the power board, on the negative side, through circuit breakers mounted in the power room, on the dividing wall between the battery and power rooms. The positive discharge leads are connected to a common earth bar supported on the wall behind the power board.

Connections are run from the power board to the distributing bars on the distribution fuse panels on both floors and, from the main earth bar, to auxiliary earth bars, one mounted at the rear of the distribution fuse panel on the first floor, and one mounted above the fuse panel on the second floor. Owing to the voltage limits of 46 to 52 volts at the D.F.P.'s, which must be maintained under all load conditions and also on account of the size of the maximum discharge current, the conductors between batteries and D.F.P.'s must be of considerable cross-section. Consequently hard drawn copper bars, supported on porcelain insulators, have been used. The negative conductors are insulated throughout by strips made of an asbestos compound.

The distribution from fuse panels to apparatus racks is effected by means of V.I.R. cables, run in cable racks. The cross-section area of these leads is such as to ensure correct operation of switches and absence of crosstalk.

The power board is shown in Figure 26. The three panels on the left are equipped with the automatic change-over switches for the two motor-alternators and the two ringing machines. On the main power panels are mounted the overload and reverse circuit breakers and field regulators for the two charging machines, together with the voltmeter, plug bus bars and switches. The arrangement of the plug bus bars and switches is such that either machine may be used to charge, or to share the load with, either battery.

The distribution fuse panel for the equipment on the first floor, the manual fuse panel supplying manual board circuits and the panel supplying ringing current and 30 volt direct current to P.B.X.'s are mounted to the right of the power board.

The distribution fuse panel serving the second floor is shown in Figure 20. In this view the guard has been removed to show the positive bus bar coming up through the floor.

Acknowledgment

The writer desires to express his thanks to the Engineer-in-Chief of the British Post Office for permission to publish this article and the accompanying illustrations.

An Artificial Traffic Machine for Automatic Telephone Studies

By E. A. ELLIMAN and R. W. FRASER

Engineering Department Standard Telephones and Cables, Ltd.

DESIGNERS of automatic telephone exchange equipments have at all times felt the need for positive data to enable them to provide the most economical, yet adequate, quantities of equipment for efficient service. Consequently close attention has been given to the theory of probability by means of which fundamental formulæ and curves have been devised, enabling the equipment engineer to determine readily the equipment quantities required to carry any known traffic with a particular switching arrangement and a specified grade of service. Various investigators engaged in probability research have produced basic formulæ, which, while being approximately in agreement for general traffic conditions, are nevertheless at variance in certain respects owing, in some cases, to the different physical assumptions made, and in other cases, to the different methods of interpreting these assumptions in developing formulæ. Each has in turn resorted to experiment to justify assumptions and to obviate laborious or impracticable mathematical work. In these experiments different methods have been employed to reproduce physically a sequence of events governed by the laws of pure chance and analogous to those obtaining in telephone traffic. So far as the writers of this article are aware, all the methods hitherto adopted required a long period of time for one experiment, and involved careful plotting on graphs of a very large number of points. As a test, the method often adopted, of obtaining from a telephone directory a random series of four-digit numbers representing the times of call originations in ten-thousandths of the busy hour, was tried and it was found that with two men employed on the work there was an average interval of 20 seconds between the recording of two successive call originations on a graph. In this method each originating call is assumed to continue for a constant holding time—usually 2 minutes— and the number of simultaneous calls in progress at any interval is indicated as shown in Figure 1. If ten switches are being considered, any call arriving whilst ten simultaneous calls are in progress is lost. This condition is reached at points "X" marked on the graph. To obtain reliable results the experiment should be continued until about 20 lost calls are recorded so that to verify conditions with a grade of service of 1 in 1,000 ($P = 0.001$) it would be necessary to record 20,000 calls on the graph. This, at the rate indicated, would occupy 222 man-hours and even if by practice this time could be reduced it will be seen that one experiment involves a considerable amount of labour and time.

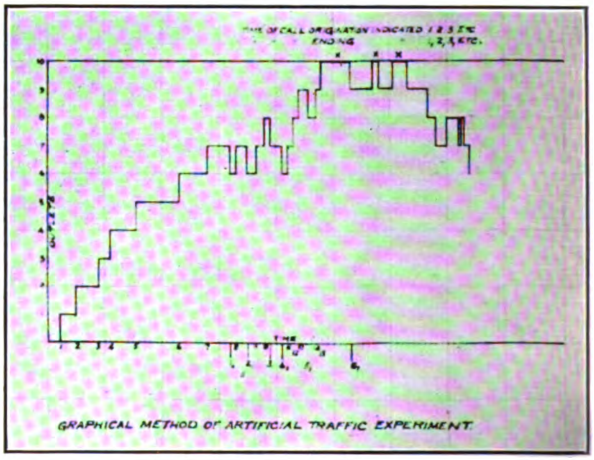


Figure 1—Simultaneous Calls in Progress at Any Interval.

The object of this article is to outline a development which has been undertaken with a view to producing a machine for the production, distribution and analysis of artificial traffic so that experiments may be carried out within a reasonably short period of time and with a considerable reduction of the tiresome work involved in graphical methods. Whilst the design of the machine described here is limited to the study of the comparatively simple trunking arrangement known as two-group grading, the principle involved readily admits of an extension of its application to more general cases.

Two main requirements have to be met in the machine:

1. It must produce a random time distribution of originated calls.
2. It must give facilities for applying the traffic so produced to particular switching arrangements, in such a manner that the traffic distribution through the system is readily obtained.

Production of Artificial Traffic

The time distribution of call originations is arranged to satisfy the following conditions:

1. Calls must originate in a purely chance manner.
2. The calling rate taken over a long period must be uniform.
3. A large number of call originations per holding time must be possible. This means that the traffic must represent that which would originate from a large number of subscribers.

To obtain numerical results readily, steel balls such as are used in ball bearings are utilised to represent calls, thereby giving each originated call a physical identity. The random traffic distribution is obtained (Figures 2 and 3) by directing a stream of balls from a funnel on to a large steel ball placed above the centre of a wire grid which supports a small number of funnels connected to rubber tubes leading to the lower part of the machine. The balls, after striking the deflecting ball, are scattered in a random manner over the grid as indicated in Figure 2 and a small proportion at chance intervals enters one or other of the funnels, which are spaced irregularly over the grid. These balls now represent originated calls, and the remainder which have fallen through the grid are directed by means of an inclined plane to a container fixed on the outside of the cabinet. The balls collected in this container are regularly transferred to the main supply at the top of the cabinet. The box containing the supply of balls is provided with an inclined glass-lined base so that an even flow of balls is supplied to the funnel. The funnel adopted, after several experiments with different shapes and types, consists of a loud-speaker horn which is hinged to the supply box so that the slope may be adjusted to the best value for an even flow. A baffle plate is fitted at the outlet from the funnel, and is operated by means of a shaft terminating in a milled nut at the side of the cabinet. This baffle plate serves to direct the stream of balls on to the deflector. The deflector is provided with both horizontal and vertical adjustments. The distribution of the balls can

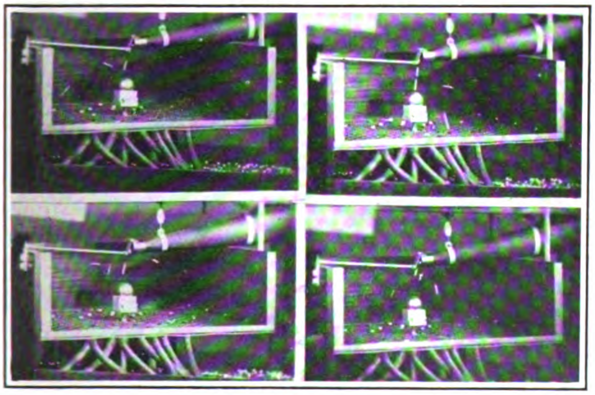


Figure 2—Random Traffic Distribution Illustrating Stream of Balls, Large Steel Deflecting Ball, Wire Grid and Rubber Tubes Leading to Lower Part of Machine.

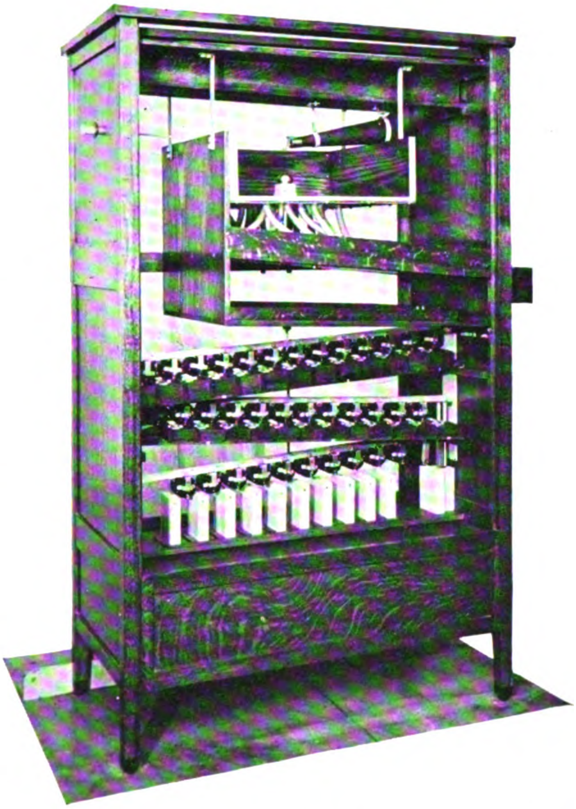


Figure 3—Artificial Traffic Machine. Lower part of mechanism represents switching equipment.

therefore be adjusted to cover the whole area of the grid over which they are scattered.

Method of Setting up Switch Arrangements

The balls which enter the rubber tubes are led through the inclined plane on which the other balls fall. They then drop into a wooden runway which directs them to the lower part of the machine representing the switching equipment. The original design represented two switching stages—a 24- or 25-point line switch stage followed by a 10-point selector stage. The arrangement is shown in Figure 3, and although this has been modified in the later design it is described here to indicate the facilities which may be provided.

In Figure 3 the multipled 25 outlets from a group of line switches is represented by an inclined aluminium runway with 25 holes, each hole being provided with a "busying" device arranged to close it for a period equal to a call holding time whenever a ball drops into it. A ball starting from the beginning of the runway proceeds along it, passes all busy outlets and enters the first free one, thus giving a mechanical representation of a call hunting by means of a line switch for a free outlet. Before they enter the line switch runway, the balls from the wooden runway pass through a separating device which ensures a certain time interval between the arrival of two balls in the line switch runway. This is done to prevent the mechanical equivalent of a double connection, which would otherwise occur in the machine more frequently than in actual practice. A ball which finds all line switch outlets engaged falls through a hole at the end of the runway into a tube leading to an overflow bin. This represents a call which has failed to find a free outlet on the first half-revolution of a line switch; but since a line switch continues to hunt till a free outlet is found, this ball must immediately be transferred to the beginning of the line switch runway and must be allowed to hunt again.

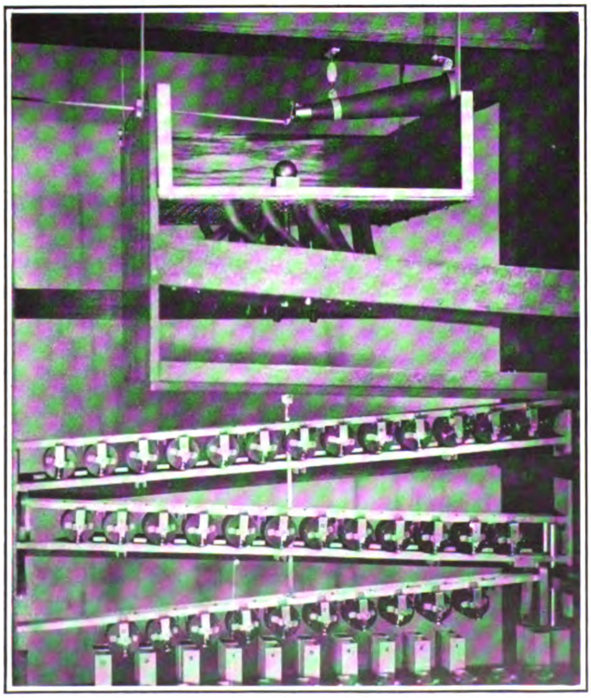


Figure 4—Artificial Traffic Machine. First three outlets shown engaged by means of "busying" device.

For convenience in designing the cabinet, the 25 outlets representing the line switch multiple are arranged in two groups, one of 13 and one of 12—the upper two runways in Figure 3. If it is desired to represent the 24-point multiple of the homing line switch, one of the 25 outlets is permanently "busied."

The outlet "busying" device shown in Figure 3 consists of an ebonite roller mounted below the outlet. Attached to the side of the roller is a short glass tube the bore of which is slightly greater than 5/16″. A 5/16″ diameter steel ball is enclosed in the tube; the remaining space is completely filled with a mixture of glycerine and water, and both ends of the tube are sealed. In the free condition, the tube takes up a vertical position due to the weight of the steel ball, and in this position the roller presents a pocket to the outlet in the runway. A steel ball on reaching a free outlet, drops into the pocket, turns the roller over and drops into a runway below, parallel to the first, and leading to the next switching stage. Meanwhile the roller having been turned over is prevented from returning to the normal position by a pin which engages a pawl, the arrangement being such that the roller can rotate in one direction only. In the locked position, the roller closes the runway outlet while the glycerine tube is held in a position slightly inclined to the horizontal. In Figure 4 the first three outlets are shown engaged. The ball enclosed in the tube rolls slowly down, the motion being restricted by the glycerine. When the ball has passed the centre of the tube its weight turns the roller over to a second normal position 180° removed from the first. In this position a second pocket is presented to the outlet which is, therefore, free again. The time taken for the roller to leave one normal position and restore to the second represents the holding time of the call. The average value of this time should be the same for all rollers to reproduce conditions corresponding to those assumed in theory.

In the original design, a ball having taken a line switch outlet is carried by means of the runway below the rollers to the top of a similar runway equipped with 10 outlets representing the multipled outlets from one level of a group of selectors. The delay between the seizure of a free line switch outlet and the subsequent seizure of a selector outlet is somewhat longer in the traffic machine than in actual automatic switching. The runways are, however, arranged so that the time between the commencement of hunting at the line switch stage and the commencement of hunting at the selector stage is the same for all calls. Thus the slower hunting speed and delay between stages does not affect the traffic distribution.

Since the traffic from subscribers' line switches is not all routed over the same level of first selectors, the artificial traffic machine must be arranged to satisfy this condition. For the purpose of traffic experiments it is not necessary to study more than one level; traffic to the other levels need not be analysed. A mixture of two sizes of balls is, therefore, used and, after leaving the line switch runway, the balls pass a separating device which routes the larger size to the selector runway and the smaller size, representing traffic to other levels, to an analysis bin. The mixture of the two sizes thus controls the average value of the fraction of the total traffic routed over the level which is being studied.

The outlets in the selector runway are tested in turn in exactly the same manner as already indicated, and when a free outlet is found, the ball, having turned the roller over, is dropped into an analysis bin placed below the roller. If all 10 outlets are busy the ball drops through a hole at the end of the runway into a separate bin. Thus the number of calls received by any one outlet or the number of lost calls is given by the number of balls found in the corresponding bin at the end of the test.

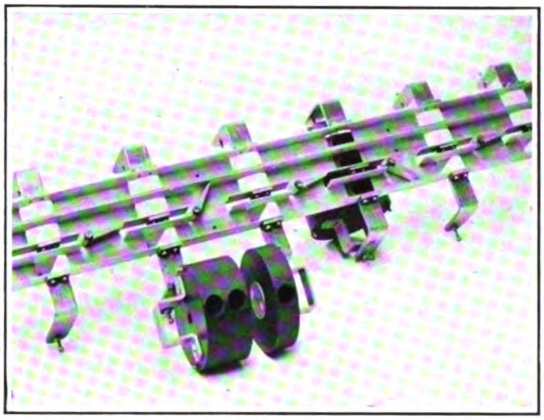


Figure 5—Double Runway Provided for Two-group Grading.

In order to carry out tests on the distribution of traffic at the line switch stage, two sets of analysis bins, corresponding to the two halves of the line switch runway, are provided. These analysis bins can be seen in Figure 3, numbered 1, 5, 10, 15, 20 and 25. When these bins are placed in position alongside the runways, the balls which take line switch outlets drop into short channels each leading to a bin corresponding to a particular outlet.

Facilities for two-group grading are provided by duplicating the whole of the mechanism representing the switching arrangements as described above. The rubber tubes from the wire grid are divided into two groups leading to two wooden runways which serve the two sets of line switch and selector runways. Each of the duplicate line switch and selector runways consists of two channels fitted close together and equipped with one set of rollers double the width of the first rollers so that the two outlets controlled by one roller may be "busied" by a ball from either channel. The double runway is mounted alongside the first, and the partition between the single runway and the adjacent channel of the double runway is provided with a series of gates, one between each pair of outlets. The arrangement is shown in Figure 5. At the beginning of the line switch or selector runways, the balls enter the two outer of the three channels so that if it is desired to run the two groups of outlets with no grading, the centre channel is not used. If some of the outlets in the two groups are to be graded, the gate before the first graded outlet is thrown across the single runway, so that a ball finding the individual outlets in that runway engaged, is deflected into the centre channel and proceeds to test the outlets which are also being tested by balls in the outer channel of the double runway. A trunking arrangement with individual outlets following graded outlets (called "reversed grading" by the British Post Office) can be provided by setting the gate after the last graded outlet across the centre channel, so that a ball which finds the graded outlets in the centre channel engaged, is returned to the single runway to test the last group of individual outlets.

Arrangements are also provided in the machine for enabling a call to be routed from either of the two line switch multiples to either of the two selector groups. Thus, a ball having taken a particular line switch outlet, may either drop into the channel immediately below it and leading to one selector runway, or, by means of a deflector which clips on to the channel below the roller, the ball on falling out of the roller may be deflected to the runway which leads to the other selector group.

The trunking scheme of the machine as described above is shown in Figure 6.

It was proved that with the design of "busying" device described above, owing to the difficulty of adjusting all rollers to have the same average holding time, it was not possible to obtain any accurate results from tests. This difficulty was caused by the slight differences in the several timing devices and the individual adjustments which were necessary for each. It was, therefore, decided to introduce a timing device with a common control, the arrangement being such as to utilise the first model as far as possible.

The timing arrangement adopted is shown in Figure 7, and consists of a series of shafts, one running below each set of rollers, and all shafts being driven through gearing from a small electric motor fitted inside the cabinet. Each shaft carries a number of wheels (one per roller) which are driven through a friction clutch. The glycerine tubes are removed from the rollers, and one of the two pockets is filled in to load the roller, so that normally it takes up a position with the other pocket open to the runway. In this free position, the corresponding wheel on the rotating shaft is prevented from turning by means of a pawl which engages with a notch in the wheel. When the outlet is taken, the roller turns over as before, and in doing so, a pin, fitted in the side, strikes the pawl, and raises it out of the notch in the wheel, which immediately moves away from the normal position. The ball having dropped out of the roller, the latter tends to return to normal, but is prevented by the pawl, which now rests on the rim of the wheel against which it is forced, both by its own weight and by the roller. The outlet is thus held "busy" until the notch in the wheel has made a complete revolution, when the pawl drops in and releases the roller, and at the same time locks the wheel again.

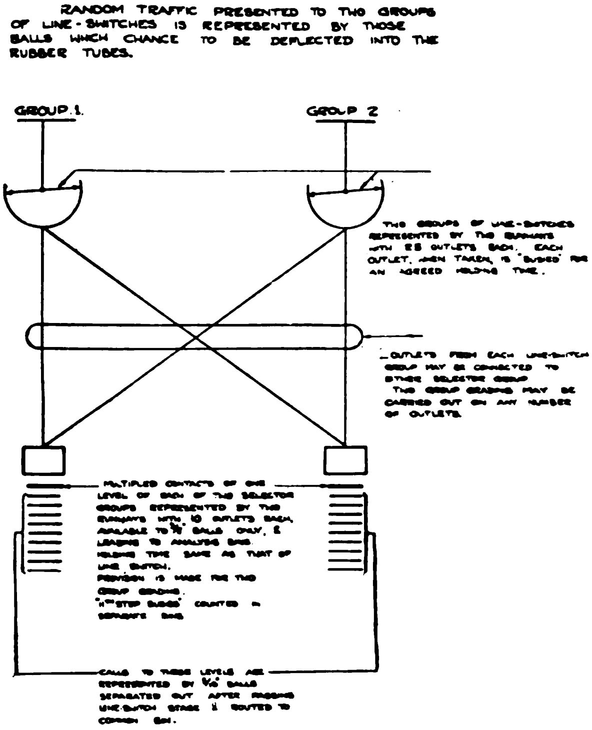

RANDOM TRAFFIC PRESENTED TO TWO GROUPS OF LINE-SWITCHES IS REPRESENTED BY THOSE BALLS WHICH CHANCE TO BE DEFLECTED INTO THE RUBBER TUBES.
GROUP 1.
GROUP 2
TWO GROUPS OF LINE-SWITCHES REPRESENTED BY TWO RUNWAYS WITH 25 OUTLETS EACH. EACH OUTLET, WHEN TAKEN, IS "BUSIED" FOR AN AGREED HOLDING TIME.
OUTLETS FROM EACH LINE-SWITCH GROUP MAY BE CONNECTED TO OTHER SELECTOR GROUP. TWO GROUP GRADING MAY BE CARRIED OUT ON ANY NUMBER OF OUTLETS.
MULTIPLED CONTACTS OF ONE LEVEL OF EACH OF THE SELECTOR GROUPS REPRESENTED BY TWO RUNWAYS WITH 10 OUTLETS EACH, AVAILABLE TO 1/10 BALLS ONLY, & LEADING TO ANALYSIS BINS. HOLDING TIME SAME AS THAT OF LINE SWITCH. PROVISION IS MADE FOR TWO GROUP GRADING. "NTH STEP BUSIES" COUNTED IN SEPARATE BINS.
CALLS TO THESE LEVELS ARE REPRESENTED BY 1/10 BALLS SEPARATED OUT AFTER PASSING LINE-SWITCH STAGE & ROUTED TO COMMON BIN.

Figure 6—Trunking Scheme of Artificial Traffic Machine

One complete turn of the shaft, therefore, represents a call holding time, and since all shafts are controlled by the same motor, the holding time of all outlets is the same. By varying the speed of the motor, the holding time may be adjusted within limits to any desired value.

The introduction of this type of "busying" device in the original model permits the use of only 23 of the 25 outlets in each line switch group (in Figure 7: outlets 12, 13 and 25 are shown permanently "busied"). The capacity of the machine is, therefore, reduced for the present to one switching stage with facilities for studying the traffic distribution in two groups of outlets, each group consisting of any number of outlets up to 22. The arrangements for direct or reversed grading between these groups remain unchanged.

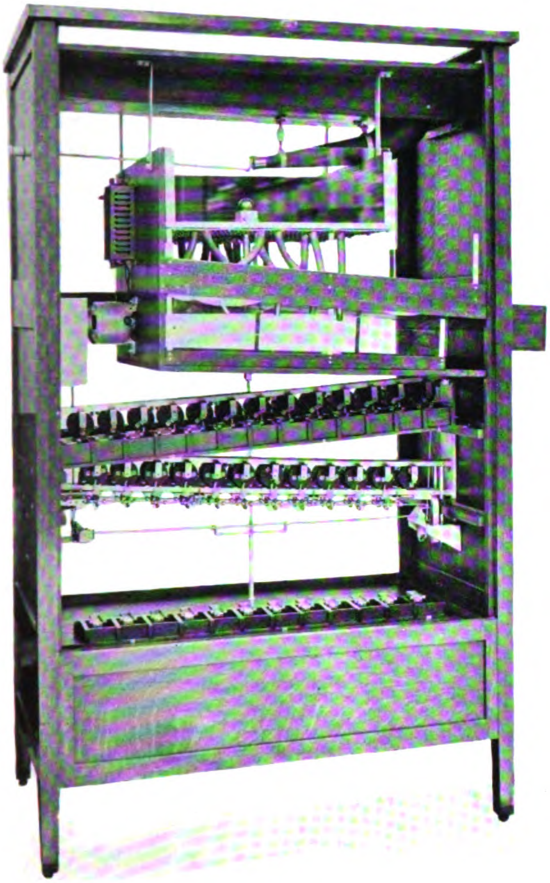


Figure 7—Artificial Traffic Machine with Common Control "Busying" Device.

Although the reduction to one switching stage reduces the scope of the machine, it is possible with the single stage to study problems associated with the standard 10-group selector or with the 20-group selector. In this way the accuracy of the underlying principle of the machine may be tested and the machine may then be applied to the solution of problems such as arise, for example, with reversed grading. If required, arrangements can be made for adding the second stage.

Method of Making Tests

Before a test is run on the machine, a preliminary experiment must be made to ascertain that a satisfactory volume of traffic is being obtained. The balls are allowed to run from the funnel, and the baffle plate and deflecting ball are adjusted to give a satisfactory distribution over the grid. The wooden runways leading to the lower part of the machine are closed to prevent the balls from proceeding further, and the time taken for a number of calls to originate is measured. From this the number of calls per holding time—i.e., the traffic—is obtained, and if any change is required to the value given, this can be effected either by adjusting the number of rubber tubes or by altering the position of some of them on the grid.

To commence a test on both line switch and selector stages, the required grading and cross-connecting arrangements are made, and the balls are allowed to run through the machine until a number of calls are in progress. During the preliminary run all the balls are collected in a common bin placed below the selector runways. These calls do not count in the test. The test interval commences from the time when all the analysis bins, mounted on a platform at the bottom of the machine, are pushed forward into position below the rollers.

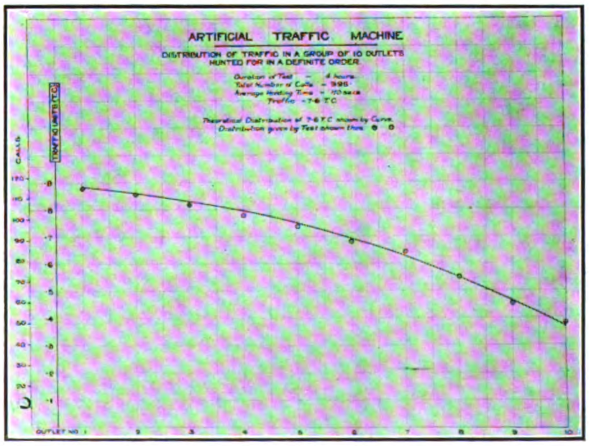


Figure 8.

At the end of the test period, the platform with the analysis bins is withdrawn and the common bin is replaced. The aperture between the baffle plate and the funnel mouth is then closed to stop the flow of balls.

A test on the line switch stage only, is carried out in the same manner except that during the preliminary run the balls are allowed to proceed to the selector stage, or in the present model, to a common starting bin. The test period commences when the group of wooden analysis bins is placed up against the runway and ends when these bins are withdrawn.

Results of Tests

The machine in its modified form has been employed to determine the distribution of traffic in certain simple cases where the solution can also be derived mathematically. Results of such experiments are reproduced in graphical form in Figures 8 and 9 and in tabular form in Tables I and II. It will be seen that in Figure 8 the mechanical analysis closely approximates to that deduced by theory; the machine, therefore, furnishes a direct means of solution for the complex cases where precise mathematical solutions are too laborious or are impossible.

TABLE I

Test of Distribution of Traffic in a Group of Ten Outlets Hunted for in a Definite Order

Summary of Results

Duration of Test	4 hours
Total Number of Originated Calls	995
Average Holding Time of Calls	110 seconds
Traffic (a)	7.6 T.C.

Distribution

Outlet No. (r)	Calls	Traffic Units (T.C.)		Calls	
		Test	Theoretical (a_r)	Test	Theoretical
1	115	.879	.884	115	115.6
2	112	.856	.860	112	112.5
3	107	.817	.828	107	108.3
4	102	.779	.796	102	104.3
5	96	.734	.748	96	98.0
6	89	.680	.692	89	90.6
7	84	.641	.625	84	81.8
8	72	.550	.548	72	71.8
9	59	.451	.461	59	60.4
10	50	.382	.369	50	48.3
O/F	109	.833	.789	109	103.1
Totals...	995	7.602	7.600	995	994.7

TABLE II

Test of Distribution of Traffic in a Two-Group Grading with Two Individual and Nine Common Outlets

Summary of Results

Duration of Test	5 hours
Number of Calls to Group 1	475
Number of Calls to Group 2	971
Total Number of Calls	1,446
Average Holding Time of Calls	104.6 seconds
Traffic to Group 1	2.82 T.C.
Traffic to Group 2	5.78 T.C.
Total Traffic	8.6 T.C.

Distribution

Outlet No.	Calls	Traffic Units (T.C.)		Calls	
		Test	Theoretical	Test	Theoretical
1 Grp. 1	124	.737	.739	124	124.1
1 " 2	146	.868	.852	146	143.1
2	145	.862	.869	145	146.0
3	142	.844	.838	142	140.9
4	137	.815	.803	137	135.0
5	128	.761	.761	128	128.0
6	124	.737	.708	124	119.0
7	113	.672	.643	113	108.0
8	99	.589	.570	99	95.8
9	83	.493	.490	83	82.4
10	67	.398	.400	67	67.3
O/F	138	.821	.927	138	155.9
Totals...	1,446	8.597	8.600	1,446	1,445.5

The points through which the theoretical curve in Figure 8 is drawn are those given in column 4 of Table I and are derived from the formula:

$$a_r = \frac{\dfrac{a^{r-1}}{r-1!}}{1 + a + \dfrac{a^2}{2!} + \ldots + \dfrac{a^{r-1}}{r-1!}} - \frac{\dfrac{a^r}{r!}}{1 + a + \dfrac{a^2}{2!} + \ldots + \dfrac{a^r}{r!}}$$

where a_r = traffic carried by the rth choice switch of a fully available group hunted for in a definite order, and

a = total traffic approaching the group.

The expression:

$$\frac{\dfrac{a^r}{r!}}{1 + a + \dfrac{a^2}{2!} + \ldots + \dfrac{a^r}{r!}}$$

represents the probability that a group of r

switches is completely occupied and can be denoted by p_r. The formula for a_r can, therefore, be expressed as:

$$a_r = a(p_{r-1} - p_r).$$

The theoretical curve in Figure 9 is deduced in a similar manner. The traffic carried by each individual first choice is calculated from the formula, and the total overflow to the common second choice is then known. The total traffic which, presented to the first choice of a single group of ten outlets, would give the same overflow to the second outlet can then be determined. This traffic is then substituted for the term "a" in the above formula to give the approximate theoretical traffic distribution over the common outlets. Figure 9 indicates the extent to which the experiment agrees with the approximate mathematical method.

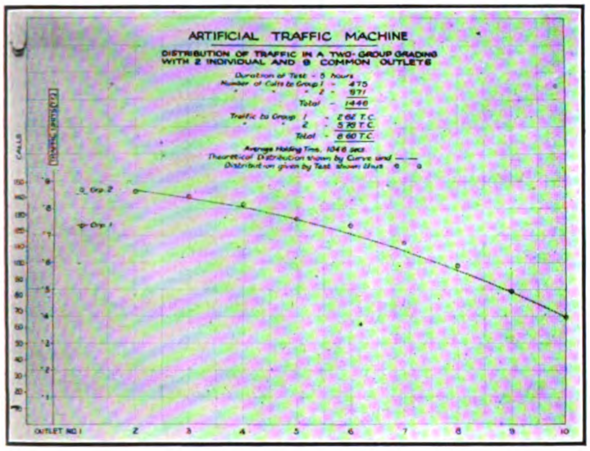


Figure 9.

Further Developments

The development of this model has led to the proposed design of an electrically controlled system in which the present arrangements for giving a random time distribution of originated calls would be retained while the switching arrangements would be represented by groups of relays and message registers, the latter giving the traffic analysis by direct readings. Such a scheme would be more flexible than the mechanical arrangement; and with the provision of a small distributing terminal assembly, would give facilities for studying any trunking arrangement.

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division American Telephone and Telegraph Company

Telephone Development of the World, by Countries

January 1, 1927

	Number of Telephones			Per Cent of Total World	Telephones per 100 Population	Increase in Number of Telephones During 1926
	Government Systems	Private Companies	Total			
NORTH AMERICA:						
United States	—	17,746,168	17,746,168	60.40%	15.3	810,250
Canada	216,438	984,650	1,201,088	4.09%	12.6	58,212
Central America	8,263	12,020	20,283	.07%	0.3	269
Mexico	1,427	56,136	57,563	.20%	0.4	3,098
West Indies:						
Cuba	530	64,686	65,216	.22%	1.8	3,102
Porto Rico	841	12,533	13,374	.05%	0.9	614
Other W. I. Places*	7,588	10,572	18,160	.06%	0.3	285
Other No. Am. Places*	100	8,405	8,505	.03%	2.4	484
Total	235,187	18,895,170	19,130,357	65.12%	12.0	876,314
SOUTH AMERICA:						
Argentina	—	204,463	204,463	.70%	2.0	15,427
Bolivia*	—	1,824	1,824	.01%	0.1	—
Brazil	632	104,577	105,209	.35%	0.3	1,593
Chile	—	36,860	36,860	.13%	0.8	1,696
Colombia	50	18,825	18,875	.06%	0.2	483
Ecuador*	1,691	2,827	4,518	.02%	0.2	—
Paraguay	183	230	413	.001%	0.03	—48
Peru	—	13,229	13,229	.05%	0.2	2,229
Uruguay	—	26,915	26,915	.09%	1.6	864
Venezuela	612	12,120	12,732	.04%	0.4	677
Other Places	2,708	—	2,708	.01%	0.6	66
Total	5,876	421,870	427,746	1.46%	0.5	22,987
EUROPE:						
Austria	158,429	—	158,429	.54%	2.3	5,386
Belgium	176,572	—	176,572	.60%	2.2	17,500
Bulgaria	10,010	—	10,010	.03%	0.2	1,010
Czechoslovakia	128,956	—	128,956	.44%	0.9	8,408
Denmark	13,253†	307,856	321,109	1.09%	9.2	4,712
Finland	—	98,556	98,556	.33%	2.8	13,556
France	818,971	—	818,971	2.79%	2.0	81,773
Germany	2,688,495	—	2,688,495	9.15%	4.2	100,479
Great Britain and No. Ireland	1,511,585	—	1,511,585	5.14%	3.3	120,429
Greece	6,328	—	6,328	.02%	0.1	828
Hungary	114,660	—	114,660	.39%	1.4	9,000*
Irish Free State (March 31, 1927)	23,830	—	23,830	.08%	0.8	1,977
Italy (June 30, 1927)	—	272,433	272,433	.93%	0.7	23,256
Jugo-Slavia	28,378	—	28,378	.10%	0.2	—1,564
Latvia (March 31, 1927)	24,192	—	24,192	.08%	1.2	5,349
Netherlands	225,348	—	225,348	.77%	3.0	11,307
Norway	101,567‡	73,933	175,500	.60%	6.3	1,748
Poland	74,153	57,798	131,951	.45%	0.5	11,721
Portugal	3,000*	19,450	22,450	.08%	0.4	1,594
Roumania	53,274	—	53,274	.18%	0.3	6,000*
Russia¶	225,409	—	225,409	.77%	0.2	32,627
Spain	—	131,519	131,519	.45%	0.6	9,437
Sweden	448,832	1,814	450,646	1.53%	7.4	16,052
Switzerland	210,486	—	210,486	.72%	5.3	10,275
Other Places in Europe*	53,709	17,846	71,555	.24%	1.0	2,765
Total	7,099,437	981,205	8,080,642	27.50%	1.6	495,625
ASIA:						
British India (March 31, 1927)	16,140	29,758	45,898	.15%	0.01	2,659
China*	85,644	39,677	125,321	.43%	0.03	7,547
Japan (March 31, 1927)	648,091	—	648,091	2.21%	1.1	11,355
Other Places in Asia*	90,946	18,275	109,221	.37%	0.1	384
Total	840,821	87,710	928,531	3.16%	0.1	21,945
AFRICA:						
Egypt	37,705	—	37,705	.13%	0.2	1,961
Union of South Africa†	88,680	—	88,680	.30%	1.2	7,991
Other Places in Africa*	59,065	1,096	60,161	.20%	0.1	6,146
Total	185,450	1,096	186,546	.63%	0.1	16,098
OCEANIA:						
Australia (June 30, 1926)	403,616	—	403,616	1.37%	6.7	40,667
Dutch East Indies	39,355	3,544	42,899	.15%	0.1	1,936
Hawaii	—	19,648	19,648	.07%	6.5	844
New Zealand (March 31, 1927)	137,307	—	137,307	.47%	9.5	7,121
Philippine Islands	4,731	13,083	17,814	.06%	0.1	848
Other Places in Oceania*	2,774	550	3,324	.01%	0.2	292
Total	587,783*	36,825	624,608	2.13%	0.8	51,708
TOTAL WORLD	8,954,554	20,423,876	29,378,430	100.00%	1.6	1,484,677

* Partly estimated.
† March 31, 1927.
‡ June 30, 1926.
¶ Including Siberia and Associated Republics.

Telephone and Telegraph Wire of the World, by Countries
January 1, 1927

	Service Operated by (See Note)	Miles of Telephone Wire			Miles of Telegraph Wire (See Note)		
		Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	57,960,000	60.41%	50.0	2,020,000	30.09%	1.7
Canada	P.G.	3,306,214	3.45%	34.7	305,933	4.56%	3.2
Central America	P.G.	39,317	.04%	0.6	21,205	.31%	0.3
Mexico	P.G.	130,265	.13%	0.8	84,292	1.25%	0.5
West Indies:							
Cuba	P.G.	216,560	.22%	6.1	12,231	.18%	0.3
Porto Rico	P.G.	27,745	.03%	1.9	1,072	.02%	0.1
Other W. I. Places*	P.G.	37,402	.04%	0.6	4,196	.06%	0.1
Other No. Am. Places*	P.G.	17,010	.02%	4.8	10,000	.15%	2.8
Total		61,734,513	64.34%	38.9	2,458,929	36.62%	1.5
SOUTH AMERICA:							
Argentina	P.	675,258	.70%	6.6	203,502	3.03%	2.0
Bolivia	P.	3,589*	.01%	0.1	7,150	.11%	0.2
Brazil	P.G.	270,617	.28%	0.7	102,362	1.52%	0.3
Chile	P.	54,096	.05%	1.1	45,342	.68%	1.0
Colombia	P.	25,707	.03%	0.3	18,973	.28%	0.2
Ecuador	P.G.	5,083*	.01%	0.2	4,555	.07%	0.2
Paraguay	P.G.	138	—	0.01	2,223	.03%	0.2
Peru	P.	39,433	.04%	0.7	11,929	.18%	0.2
Uruguay	P.	47,891	.05%	2.8	6,404	.10%	0.4
Venezuela	P.G.	31,808	.03%	1.1	6,281	.09%	0.2
Other Places	G.	4,751	.01%	1.0	786	.01%	0.2
Total		1,158,371	1.21%	1.5	409,507	6.10%	0.5
EUROPE:							
Austria	G.	443,814	.46%	6.5	48,538	.72%	0.7
Belgium	G.	661,746	.69%	8.4	25,901	.38%	0.3
Bulgaria	G.	34,962	.04%	0.6	12,477	.19%	0.2
Czechoslovakia	G.	258,900	.27%	1.8	44,204	.66%	0.3
Denmark	P.G.	816,707	.85%	23.5	9,011	.13%	0.3
Finland	P.	120,343	.13%	3.4	8,985	.13%	0.3
France	G.	2,252,348	2.35%	5.5	441,638	6.58%	1.1
Germany	G.	9,803,007	10.22%	15.3	561,183	8.36%	0.9
Great Britain and No. Ireland†	G.	6,610,000	6.89%	14.6	354,000	5.27%	0.8
Greece	G.	10,169	.01%	0.2	29,799	.44%	0.5
Hungary	G.	255,325	.27%	3.0	51,439	.77%	0.6
Irish Free State (March 31, 1927)	G.	74,981	.08%	2.5	23,660	.35%	0.8
Italy (June 30, 1927)*	P.G.	715,000	.74%	1.8	270,000	4.02%	0.7
Jugo-Slavia	G.	95,316	.10%	0.7	54,940	.82%	0.4
Latvia (March 31, 1927)	G.	114,493	.12%	5.9	5,439	.08%	0.3
Netherlands	G.	470,000*	.49%	6.2	29,218	.43%	0.4
Norway (June 30, 1926)	P.G.	480,474	.50%	17.3	25,034	.37%	0.9
Poland	P.G.	473,450	.49%	1.7	54,420	.81%	0.2
Portugal*	P.G.	72,377	.08%	1.2	20,000	.30%	0.3
Roumania	G.	166,814	.17%	0.9	46,904	.70%	0.3
Russia¶	G.	1,064,000	1.11%	0.7	413,800	6.19%	0.3
Spain	P.	250,000*	.26%	1.1	74,914	1.11%	0.3
Sweden	G.	1,020,912	1.06%	16.8	54,970	.82%	0.9
Switzerland	G.	585,737	.61%	14.8	23,431	.35%	0.6
Other Places in Europe*	P.G.	156,295	.16%	2.2	14,295	.21%	0.2
Total		27,007,170	28.15%	5.2	2,698,200	40.19%	0.5
ASIA:							
British India (March 31, 1927)	P.G.	324,336	.34%	0.1	383,941	5.72%	0.1
China*	P.G.	215,439	.22%	0.05	85,000	1.27%	0.02
Japan (March 31, 1927)	G.	2,166,771	2.26%	3.6	183,478	2.73%	0.3
Other Places in Asia*	P.G.	252,384	.26%	0.2	115,041	1.71%	0.1
Total		2,958,930	3.08%	0.3	767,460	11.43%	0.1
AFRICA:							
Egypt	G.	147,653	.15%	0.7	27,750	.41%	0.1
Union of South Africa†	G.	332,108*	.35%	4.4	49,042	.73%	0.6
Other Places in Africa*	P.G.	119,438	.13%	0.1	127,147	1.90%	0.1
Total		599,199	.63%	0.4	203,939	3.04%	0.1
OCEANIA:							
Australia (June 30, 1926)	G.	1,714,975	1.79%	28.3	118,141	1.76%	2.0
Dutch East Indies	P.G.	189,315	.20%	0.3	20,597	.31%	0.04
Hawaii	P.	62,225	.06%	20.7	0	.00%	0.0
New Zealand (March 31, 1927)	G.	475,649	.49%	32.9	26,336	.39%	1.8
Philippine Islands	P.G.	35,208	.04%	0.3	9,694	.14%	0.8
Other Places in Oceania*	P.G.	5,877	.01%	0.3	1,352	.02%	0.1
Total		2,483,249	2.59%	3.2	176,120	2.62%	0.2
TOTAL WORLD		95,941,432	100.00%	5.1	6,714,155	100.00%	0.4

Note: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and Government.

* Partly estimated.

† March 31, 1927.

¶ Including Siberia and Associated Republics.

Telephone Development of Large Cities
January 1, 1927

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINA:			
Buenos Aires	2,000,000	112,137	5.6
AUSTRALIA:			
Adelaide	317,000	27,385	8.6
Brisbane	274,000	20,122	7.3
Melbourne	944,000	80,301	8.8
Sydney	1,071,000	94,812	8.9
AUSTRIA (January 1, 1926):			
Gratz	157,000	7,146	4.6
Vienna	1,919,000	98,226	5.1
BELGIUM:			
Antwerp	499,000	25,738	5.2
Brussels	903,000	61,267	6.8
Charleroi	186,000	5,174	2.8
Ghent	268,000	7,379	2.8
Liege	411,000	12,187	3.0
CANADA:			
Montreal	848,000	150,681	17.8
Ottawa	176,000	34,949	19.9
Toronto	640,000	163,744	25.6
CHINA:*			
Canton	934,000	2,900	0.3
Shanghai	1,575,000	25,731	1.6
Tientsin	838,000	8,810	1.1
Peking	1,350,000	42,000	3.1
CUBA:			
Havana	581,000	45,043	7.8
CZECHOSLOVAKIA:			
Prague	711,000	30,345	4.3
DANZIG, FREE CITY OF	376,000	17,010	4.5
DENMARK:			
Copenhagen	767,000	124,021	16.2
FRANCE:			
Bordeaux	256,000	12,700	5.0
Lille	202,000	11,388	5.6
Lyons	571,000	21,266	3.7
Marseilles	652,000	19,859	3.0
Paris	2,871,000	284,261	9.9
GERMANY:			
Berlin	4,064,000	428,949	10.6
Bremen	298,000	28,279	9.5
Breslau	563,000	37,903	6.7
Chemnitz	335,000	23,813	7.1
Cologne	707,000	58,837	8.3
Dresden	625,000	52,737	8.4
Dusseldorf	437,000	38,272	8.8
Essen	476,000	24,751	5.2
Frankfort-on-Main	473,000	51,859	11.0
Hamburg-Altona	1,278,000	143,755	11.2
Hannover	427,000	31,698	7.4
Leipzig	686,000	59,155	8.6
Magdeburg	297,000	19,136	6.4
Munich	700,000	63,798	9.1
Nuremburg	471,000	31,668	6.7
Stuttgart	345,000	36,331	10.5
GREAT BRITAIN AND NORTHERN IRELAND (March 31, 1927):			
Belfast	419,000	12,944	3.1
Birmingham	1,080,000	40,537	3.7
Blackburn	128,000	3,831	3.0
Bolton	180,000	4,994	2.8
Bradford	317,000	15,793	5.0
Bristol	394,000	14,731	3.7
Edinburgh	424,000	22,623	5.3
Glasgow	1,130,000	48,178	4.3
Hull	344,000	15,190	4.4
Leeds	487,000	17,872	3.7
Liverpool	1,126,000	49,061	4.4
London	7,480,000	532,066	7.1
Manchester	1,066,000	52,424	4.9
Newcastle	463,000	16,733	3.6
Nottingham	296,000	12,643	4.3
Plymouth	212,000	5,150	2.4
Sheffield	496,000	15,740	3.2
HUNGARY:			
Budapest	985,000	49,120	5.0
Szegedin	126,000	2,359	1.9
IRISH FREE STATE (March 31, 1927):			
Dublin	410,000	13,325	3.3
JAPAN (March 31, 1927):			
Kobe	659,000	25,036	3.8
Kyoto	717,000	29,107	4.1
Nagoya	835,000	24,980	3.0
Osaka	2,260,000	86,100	3.8
Tokio	2,143,000	125,649	5.9
Yokohama	529,000	12,696	2.4
LATVIA (March 31, 1927):			
Riga	343,000	11,215	3.3

* Partly estimated.

Telephone Development of Large Cities—(Concluded)

January 1, 1927

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
NETHERLANDS:			
Amsterdam	727,000	39,804	5.5
The Hague	409,000	31,036	7.6
Rotterdam	563,000	33,833	6.0
NEW ZEALAND (March 31, 1927):			
Auckland	202,000	15,957	7.9
Christchurch	122,000	10,290	8.4
Wellington	127,000	15,997	12.6
NORWAY (June 30, 1926):			
Oslo	252,000	40,872	16.2
PHILIPPINE ISLANDS:			
Manila	332,000	12,689	3.8
POLAND:			
Warsaw	1,029,000	38,487	3.7
ROUMANIA:*			
Bucharest	800,000	12,532	1.6
RUSSIA:			
Kazan	175,000	1,625	0.9
Kharkov	410,000	5,040	1.2
Leningrad	1,616,000	47,150	2.9
Moscow	2,019,000	54,936	2.7
Odessa	411,000	3,200	0.8
SPAIN:			
Barcelona	753,000	19,758	2.6
Madrid	800,000	19,432	2.4
Seville	214,000	1,861	0.9
Valencia	265,000	3,939	1.5
SWEDEN:			
Göteborg	231,000	29,913	13.0
Malmo	117,000	15,416	13.2
Stockholm (excluding Bromma and Brännkyrka)	389,000	111,487	28.7
SWITZERLAND:			
Basel	140,000	15,262	10.9
Berne	108,000	12,482	11.6
Geneva	126,000	16,084	12.8
Zurich	211,000	26,987	12.8
UNITED STATES:†			
New York	5,942,000	1,502,376	25.3
Chicago	3,120,000	848,017	27.2
Los Angeles	1,210,000	307,471	25.4
Total of the 8 cities with over 1,000,000 population	17,754,000	4,105,693	23.1
San Francisco	721,000	229,935	31.9
Cincinnati	664,000	145,707	21.9
Milwaukee	639,000	129,151	20.2
Total of the 10 cities with 500,000–1,000,000 population	6,717,000	1,286,054	19.1
Washington	496,000	139,032	28.0
Minneapolis	470,000	119,666	25.5
Portland, Ore.	355,000	90,161	25.4
Omaha	230,000	62,169	27.1
Total of the 30 cities with 200,000–500,000 population	8,882,000	1,797,362	20.2
Total of the 48 cities with over 200,000 population	33,353,000	7,189,109	21.6

* Partly estimated.

† There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups and the development of certain representative cities within each of such groups.

Telephone Development of Large and Small Communities

January 1, 1927

Country	Service Operated by (See Note)	Number of Telephones: In Communities of 50,000 Population and Over	Number of Telephones: In Communities of less than 50,000 Population	Telephones per 100 Population: In Communities of 50,000 Population and Over	Telephones per 100 Population: In Communities of less than 50,000 Population
Austria (Jan. 1, 1926)	G.	112,664	40,379	5.0	0.9
Belgium	G.	130,742	45,830	4.1	1.0
Canada	P.G.	565,496	635,592	21.6	9.2
Czechoslovakia	G.	52,966	75,990	3.9	0.6
Denmark	P.G.	140,525	180,584	15.7	7.0
France	G.	476,000	342,971	5.5	1.1
Germany	G.	1,640,863	1,047,632	8.0	2.4
Great Britain and No. Ireland*	G.	1,110,742	432,049	4.7	1.8
Japan (March 31, 1927)	G.	426,679	221,412	3.6	0.5
Netherlands	G.	145,685	79,663	5.5	1.6
New Zealand (March 31, 1927)	G.	49,634	87,673	9.3	9.6
Norway	P.G.	57,396	118,104	14.2	5.0
Poland	P.G.	70,344	61,607	2.3	0.2
Sweden	G.	169,229	281,417	19.9¶	5.4
Switzerland	G.	88,239	122,247	11.4	3.8
United States	P.	9,306,289	8,439,879	20.6	11.9

Note: P. indicates telephone service operated by private companies, G. by the Government, and P.G. by both private companies and the Government.

* March 31, 1927. ¶ The majority of this development is due to Stockholm.

Telephone Conversations and Telegrams
Year 1926

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent of Total Wire Communications: Telephone Conversations	Per Cent of Total Wire Communications: Telegrams	Wire Communications Per Capita: Telephone Conversations	Wire Communications Per Capita: Telegrams	Wire Communications Per Capita: Total
Australia	326,439,000	18,334,000	344,773,000	94.7	5.3	54.5	3.1	57.6
Austria	428,547,000	4,016,000	432,563,000	99.1	0.9	63.2	0.6	63.8
Belgium	158,144,000	5,700,000	163,844,000	96.5	3.5	20.2	0.7	20.9
Canada	1,844,000,000	13,219,000	1,857,219,000	99.3	0.7	195.1	1.4	196.5
Czechoslovakia	218,591,000	5,043,000	223,634,000	97.7	2.3	15.3	0.3	15.6
Denmark	473,752,000	2,237,000	475,989,000	99.5	0.5	137.0	0.6	137.6
France	687,243,000	54,606,000	741,849,000	92.6	7.4	16.9	1.3	18.2
Germany	2,052,351,000	36,324,000	2,088,675,000	98.3	1.7	32.2	0.6	32.8
Gt. Britain and No. Ireland	1,217,105,000	57,984,000	1,275,089,000	95.5	4.5	26.9	1.3	28.2
Hungary	118,264,000	5,062,000	123,326,000	95.9	4.1	14.1	0.6	14.7
Japan	2,283,509,000	60,891,000	2,344,400,000	97.4	2.6	37.9	1.0	38.9
Netherlands	412,843,000	5,455,000	418,298,000	98.7	1.3	55.3	0.7	56.0
Norway	290,355,000	3,788,000	294,143,000	98.7	1.3	104.5	1.4	105.9
Sweden	664,483,000	3,946,000	668,429,000	99.4	0.6	109.6	0.6	110.2
Switzerland	163,110,000	2,942,000	166,052,000	98.2	1.8	41.3	0.8	42.1
United States	23,700,000,000	215,000,000	23,915,000,000	99.1	0.9	205.4	1.9	207.3

Note: Telephone conversations include local and toll or long distance conversations. Number of telephone conversations in the United States includes completed messages only.

Statistics of Bell Telephone System in United States

	Jan. 1, 1911	Jan. 1, 1921	Jan. 1, 1926	Jan. 1, 1927	Jan. 1, 1928	Increase during 1927
NUMBER OF TELEPHONES:						
Bell Companies:						
Telephones (Manual Service)	3,933,056	8,176,884	10,538,935	10,841,130	11,175,886	334,756
Telephones (Dial Service)	0	157,095	1,496,289	1,975,122	2,550,170	575,048
Total Bell Companies	3,933,056	8,333,979	12,035,224	12,816,252	13,726,056	909,804
Bell Connecting Companies and Lines*	1,949,663	4,267,956	4,685,000	4,758,000	4,639,430	—118,570
Total	5,882,719	12,601,935	16,720,224	17,574,252	18,365,486	791,234
NUMBER OF CENTRAL OFFICES	4,933	5,702	6,017	5,998	6,115	117
MILES OF POLE LINES	282,877	358,091	386,064	385,882	392,514	6,633
MILES OF EXCHANGE WIRE:						
Wire in Underground Cable	5,630,851	14,384,135	28,425,392	31,845,228	35,161,956	3,316,728
Wire in Aerial Cable	2,800,000	5,586,531	9,462,213	10,785,029	12,121,584	1,336,555
Open Wire	1,247,367	1,633,802	1,953,235	1,933,977	1,995,839	61,862
Total Exchange Wire	9,678,218	21,604,468	39,840,840	44,564,234	49,279,379	4,715,145
MILES OF TOLL WIRE:						
Wire in Underground Cable	386,088	1,363,398	2,057,196	2,323,368	2,725,045	401,677
Wire in Aerial Cable	70,000	299,385	1,209,332	1,543,358	2,321,857	778,499
Open Wire	1,507,906	2,110,153	2,366,172	2,430,190	2,496,614	66,424
Total Toll Wire	1,963,994	3,772,936	5,632,700	6,296,916	7,543,516	1,246,600
TOTAL MILES OF WIRE	11,642,212	25,377,404	45,473,540	50,861,150	56,822,895	5,961,745
AVERAGE DAILY TELEPHONE CONVERSATIONS: †						
Exchange Conversations	21,681,471	31,835,353	46,702,307	49,979,855	52,581,234	2,601,379
Toll Conversations	602,539	1,327,247	2,098,163	2,374,979	2,614,443	239,464
Total Conversations	22,284,010	33,162,600	48,800,470	52,354,834	55,195,677	2,840,843
NUMBER OF EMPLOYEES	120,311	231,316	293,095	300,628	308,911	8,283

* These are telephones of companies and rural lines which have arrangements with the Bell Companies for the interchange of toll messages, comprising on January 1, 1928, 8,892 companies and 30,416 rural lines. All other statistics in the table exclude data for these connecting companies and rural lines.

† For preceding calendar year.

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A Journal of Progress in the Telephone, Telegraph and Radio Art

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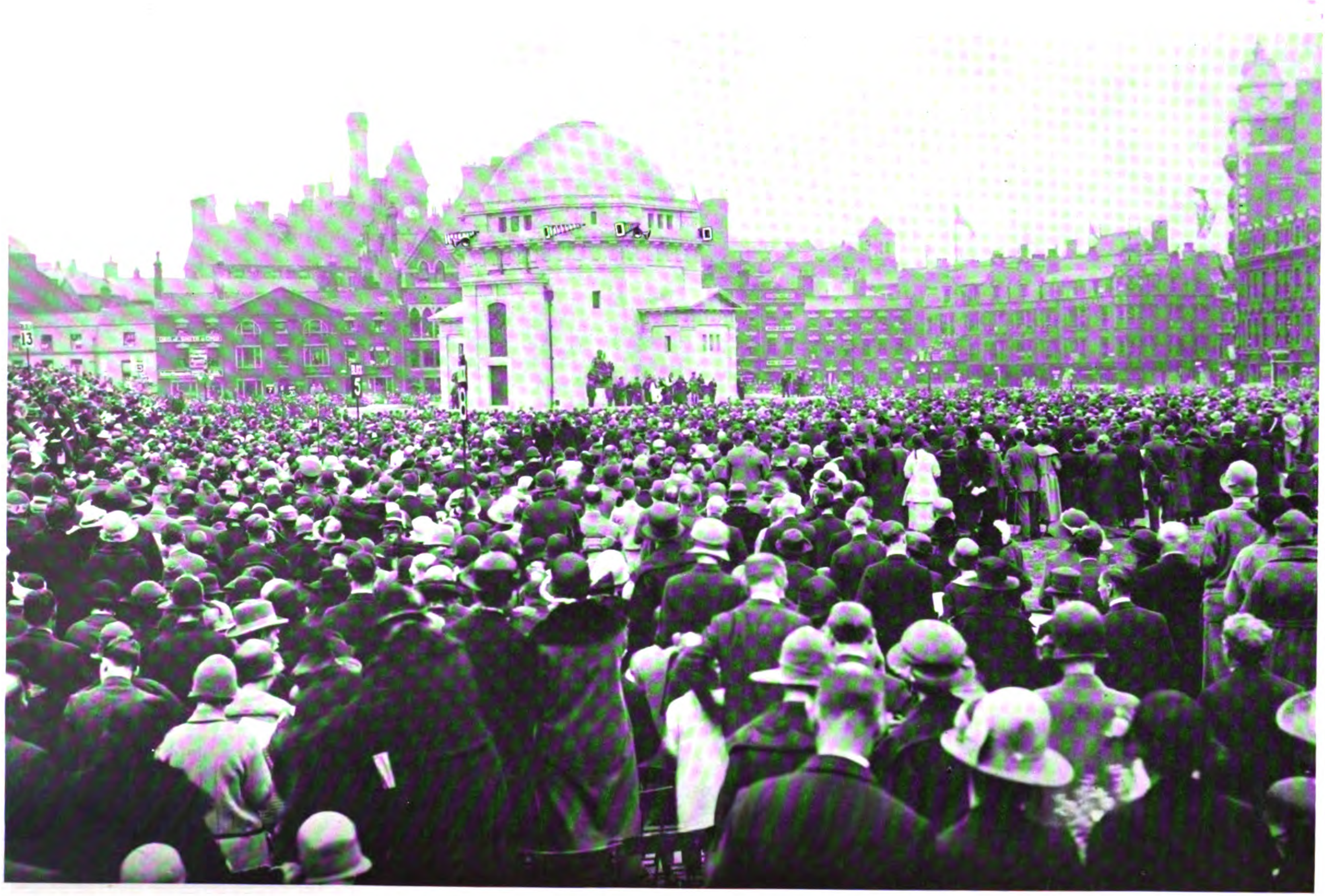

Frontispiece—H.R.H. Prince Arthur of Connaught Opening the Hall of Memory, Birmingham.

Public Address Developments

By W. E. PAGE

Standard Telephones and Cables, Ltd.

THE article on Public Address Systems in Europe which appeared in a previous issue of *Electrical Communication*,[1] described progress to the latter part of 1924. Since that time the use of Public Address Equipment has grown to such an extent, that very few organisers of large gatherings of any importance attempt to complete their programme without this voice-amplifying device. Two historical and world-renowned buildings in London, the Guildhall and the Mansion House, are now equipped with permanent installations of the Public Address System. Practically every celebrity who has visited England has been entertained at one or other of these buildings, and a great many of these guests have spoken over the equipments fitted in the banqueting halls. In both of these buildings the equipment is that known as "No. 3," and is arranged by means of microphone switching panels to accommodate as many as ten microphones. The loud speakers are arranged in suitable groups, and are controlled by a switching and volume control panel, so that the proper set of loud speakers is brought into use for any particular speaker.

In November, 1924, there was given in the Underwriting Room of Lloyds Shipping Exchange, London, a demonstration of the No. 3 System, which was installed to assist the Caller, who sits high in a rostrum announcing the names of underwriters who are in demand. The success of this demonstration was such that the equipment was adopted, and it proved so valuable in actual practice over an extended period, that in the palatial new Lloyds building (Figures 1 and 2), which was opened at Easter 1928, the larger No. 2 System was installed. Sixteen folded box-type projectors that serve the whole of the Underwriters' Room are suspended vertically from beneath the electroliers by means of a gilt rope with tassel falling over the box horns. The control room for this equipment, containing the duplicate double current motor-generator sets, is on the floor below the main hall, immediately beneath the rostrum in which is located the famous Lutine bell, which is tolled whenever a ship is posted as missing. When His Majesty the King laid

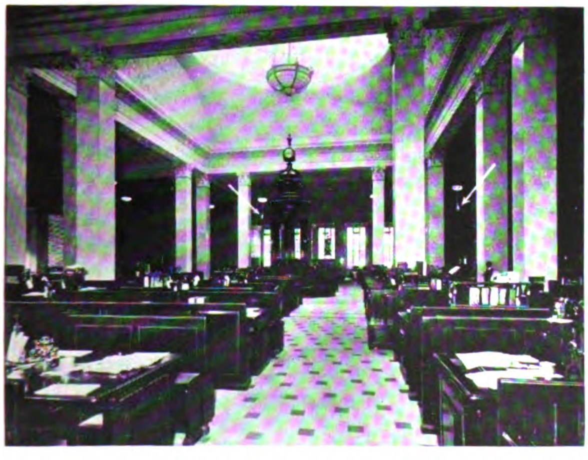

Figure 1—Lloyds Exchange. Underwriters Room Showing Loud Speakers.

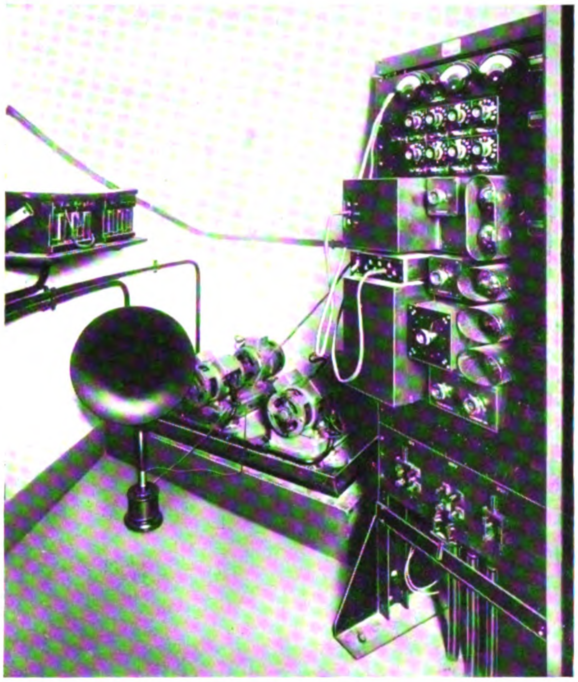

Figure 2—Lloyds Exchange. Control Room

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[1] "Demonstrations of the Public Address System in Europe," A. F. Rickard, *Electrical Communication*, Vol. 4, No. 2. October, 1925.

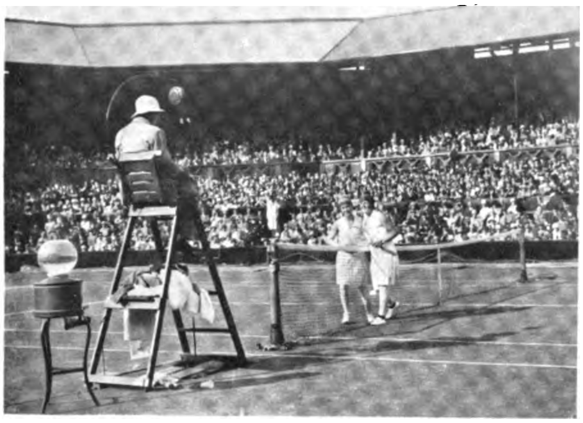

Figure 4—Wimbledon, 1927. The players are Fräulein Aussem and Betty Nuthall.

the foundation stone of this building on April 23, 1925, the amplifying of the addresses from the royal dais (Figure 3) to the large number of visitors accommodated on the circular grandstand built for the occasion, was effected by the No. 2 System.

The International Railway Congress at the Crystal Palace and the Railway Centenary Celebration at Darlington in 1925, where the No. 2 System was used, illustrate applications of such installations. At both of these gatherings hundreds of representatives from practically every country in the world were present.

The dedication and opening ceremony in 1925 of the Birmingham Hall of Memory to men of Birmingham who lost their lives in the war, was presided over by H.R.H. Prince Arthur of Connaught. A gathering of from 40,000 to 50,000 heard every word throughout a very impressive ceremony, by the aid of the No. 1 System. The large horns of the loud speakers (see Frontispiece) were mounted round the top parapet of the memorial, in correct relation to the area on the ground they were required to cover.

Figure 3—H.M. King George V Laying the Foundation Stone for Lloyds New Building, London.

Scarborough, on the Yorkshire coast, has a special No. 2 installation. The equipment is installed on the "Spa," and is used for reproducing orchestral music and other items along the whole length of this promenade, into the various large cafés, and, when required, into the Central Concert Hall.

The orchestra can play either from the stage of the Concert Hall or from the Band Stand on the promenade itself. In bad weather the orchestra occupies the indoor position. A microphone is provided, however, for both positions, and it is only necessary to switch-in the appropriate microphone to distribute the music from either. Formerly, in the height of the season only about 2,000 of the 5,000 visitors could be accommodated with seating that would ensure proper hearing; for owing to restrictions imposed by sea-noise, and occasionally by mists, the Band Stand is screened for a considerable arc of a circle, with consequent restriction of seating space for perfect hearing. The equipment, therefore, has proved a great boon, for it has enabled visitors and townsfolk to hear at all points along the Spa and elsewhere. Radio apparatus forms part of the equipment, and is used on occasions for broadcasting important radio items. The Spa equipment was used last year for the Annual Conference of the British Conservative Party which was held at Scarborough. The Prime Minister's address

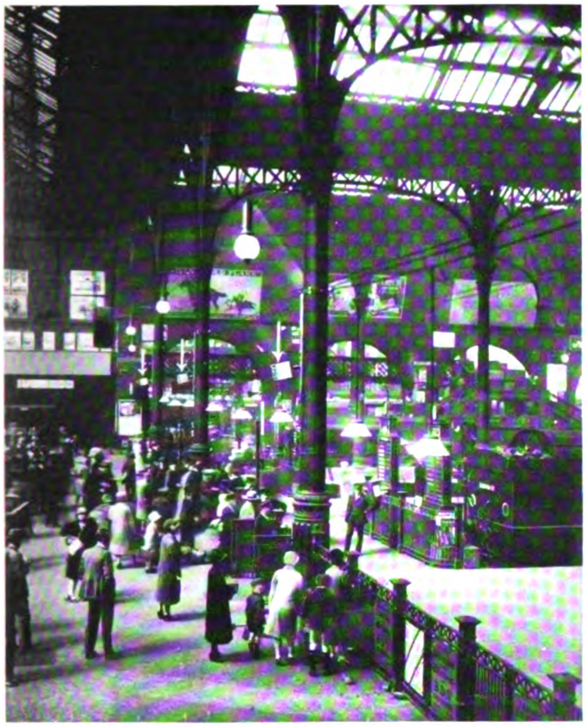

Figure 6—London and North Eastern Railway. East Side of Station Showing Loud Speakers.

was sent from the Futurist Picture House over Post Office lines to the Spa, and was broadcast to approximately 14,000 people by the No. 2 equipment.

Liverpool Cathedral No. 2 installation[2] illustrates the possibilities of the Public Address apparatus in churches and cathedrals, which unfortunately generally suffer severely from echoes and reverberations, and serves, as an example of how difficult acoustic problems can be solved. Microphones are placed permanently at the Lectern and at the Bishop's Throne, also at the High Altar. At present eight box projectors are installed, and this number will be increased when the building extensions are completed. The system contains over 25,000 feet of lead-covered cable, all of which, with the exception of lengths in the airway ducts. is concealed by masonry work. As a result of the high quality of reproduction given by the equipment, installations have been made in several churches and cathedrals, the more important being Worcester, Bristol and Norwich cathedrals. The smaller Special No. 4 Systems are installed in these instances.

The equipment used at the world-renowned Wimbledon Lawn Tennis Tournament (Figure 4), was widely appreciated; for previously, owing to the umpire's declarations being inaudible to many of the seat holders, they found it impossible to follow the games. No. 2 equipment was first installed on trial. There were many difficulties—including the fear, fortunately not substantiated, that the reproduction might disturb play on neighbouring courts—and officials were extremely pessimistic regarding results. The demonstration was completely successful, however, and from the Press, the officials, the players, and the public, it received exceptional praise.

Lunatic asylums do not at first sight appear to present very great possibilities in connection with Public Address equipments, but a definite sphere of usefulness has been found in this field There has recently been installed a system in a mental hospital in Lancashire which has proved such a success and so valuable to the unfortunate

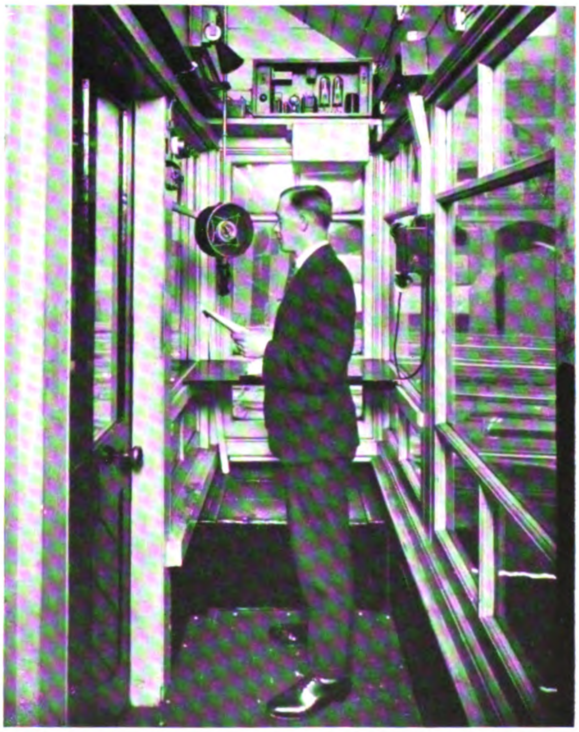

Figure 5—London and North Eastern Railway. Liverpool Street Station Control Room.

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[2] "The Public Address System in Liverpool Cathedral," Ashley F. Rickard, *Electrical Communication*, Vol. 5, No. 2, October, 1926.

patients that mental authorities are inspecting the apparatus and its working, with the idea of introducing it into other institutions. Transmission is eagerly looked forward to by the patients, and every day the system is in operation spreading a little cheer among these unfortunates by means of radio items, local orchestral music, or their own church service. Almost immediately after this equipment was put into use, a request was made to provide apparatus for a similar institution, because of the good derived by the patients from the first installation.

A demonstration of an entirely different character took place on March 28, 1927, on board S. S. "Leviathan" in dock at Southampton. A banquet attended by over 600 people was held to commemorate the one-hundredth crossing. The system was installed to allow the speeches to be heard in every part of the main banqueting hall. A telephone conversation between officials in New York and the Chairman, via the Transatlantic Radio Circuit, was repeated as received, over the Public Address System.

The latest development associated with Public Address apparatus is an equipment arranged for the use of railway companies for train announcements at busy stations. On all lines, great difficulty is experienced at certain of the larger stations in the distribution of explicit directions to the traveling public respecting the departure and arrival of trains. At many of the main stations, it is found necessary to modify existing arrangements at the last minute, and the existing facilities for advising the public quickly of these rearrangements have always been recognized as inadequate. Recent successful demonstrations carried out at York, Newcastle, London Bridge and Scarborough have created quite a sensation at the Railway Headquarters, and equipments have been ordered and installed at both Liverpool Street Station, London, and Barry Island Station, Wales.

In the case of the London and North Eastern Railway, the system which has been installed at Liverpool Street Station and which is shown in part in Figures 5 and 6, possesses several very important features. The suburban traffic handled at this terminus is greater than that at any other station in the world, the daily passengers being over 250,000. Notwithstanding the great handicap of its being a "bottle-necked" station, having only three pairs of lines in and three pairs of lines out, the eighteen platforms handle 1,215 steam trains per day, with 150 seaside specials on Saturdays. The organization is such that a two-minute up and down service on one line and a three-minute service on the others is maintained.

Figure 7—Federal Parliament at Canberra, Australia.

Loud speakers (Figure 6) are distributed over the east and west sides comprising eighteen platforms. The control equipment (Figure 5) is in an annex to the main signal cabin, from which is marshalled either directly or indirectly, every train entering or leaving the station.

Important demonstrations were carried out at Belfast and Blackpool on May 19 and July 6, 1928, respectively. At Belfast, the speeches at the ceremony of the laying of the foundation stone of the Houses of Parliament for Northern Ireland were successfully amplified to a gather-

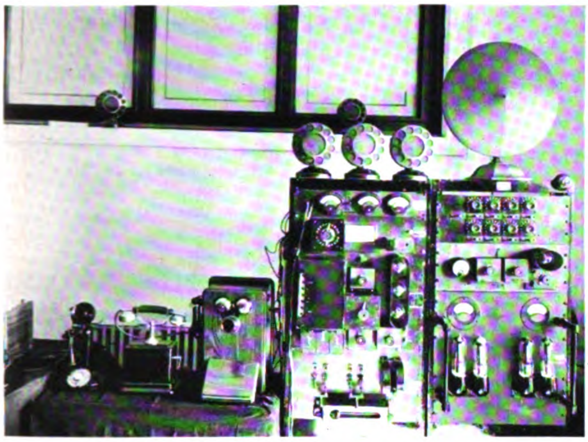

Figure 8—Federal Parliament at Canberra, Australia, Control Room.

ing of over 80,000 people. In the case of Blackpool, throughout the Air Pageant, over 120,000 people were kept in touch, by means of the No. 1 System, with every detail of each event, and with the musical programme from the Military Band. This was the first public occasion in England on which the high efficiency moving coil type loud speaking receiver, known as the No. 555-W, was adopted for such a purpose. Congratulations received from all quarters testified to the excellence of this latest type of receiver.

At the opening of the Federal Parliament of Canberra, by His Royal Highness the Duke of York on May 9, 1927, the No. 1 System made it possible for over 100,000 people to follow the ceremony by hearing perfectly every word addressed to any one of the seven microphones. Not only did that system provide the local amplification, but, to obviate the necessity for the duplication of microphones, it was arranged with the Australian Postmaster-General's Department, that the power input to the broadcasting telephonic network should be taken off one of the output circuits of the Public Address System, thus obviating the duplication of the amplifier system, and permitting of one control. The extent of this part of the system is shown in Figures 7 to 10, inclusive. The route length of lines comprising the network was 1,775 miles. The broadcasting covered a reception area of approximately 1,000,000 square miles, and it is estimated that by this means approximately 2,000,000 people listened to the ceremony.

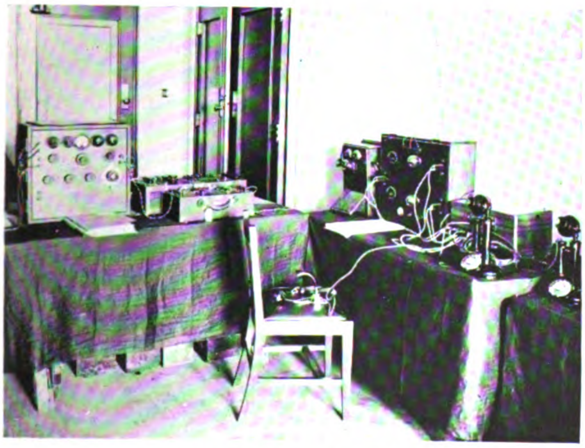

Figure 9—Federal Parliament at Canberra, Showing Apparatus Used for Broadcasting Telephone System.

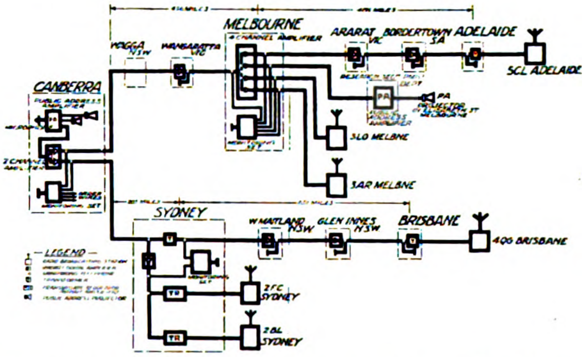

Figure 10—Federal Parliament at Canberra. Plan showing diagrammatic layout of System.

Figure 8 illustrates the Public Address equipment. It also shows the monitoring loud speaker and observation telephones. The apparatus for the broadcasting telephone system was placed in the same room, and is shown in Figure 9. By the courtesy of the Australian Postmaster-General's Department, a brief description of this equipment can be given.

Mounted on the table in the foreground is the special two-channel amplifier, and the monitoring set (Figure 9). The two-channel amplifier was specially designed by the Research Section of the Australian Postmaster-General's Department, and its input impedance was such that it in no way affected the operation of the Public Address System. Each channel of the amplifier had a separate potentiometer for controlling its gain. The monitoring set was designed to

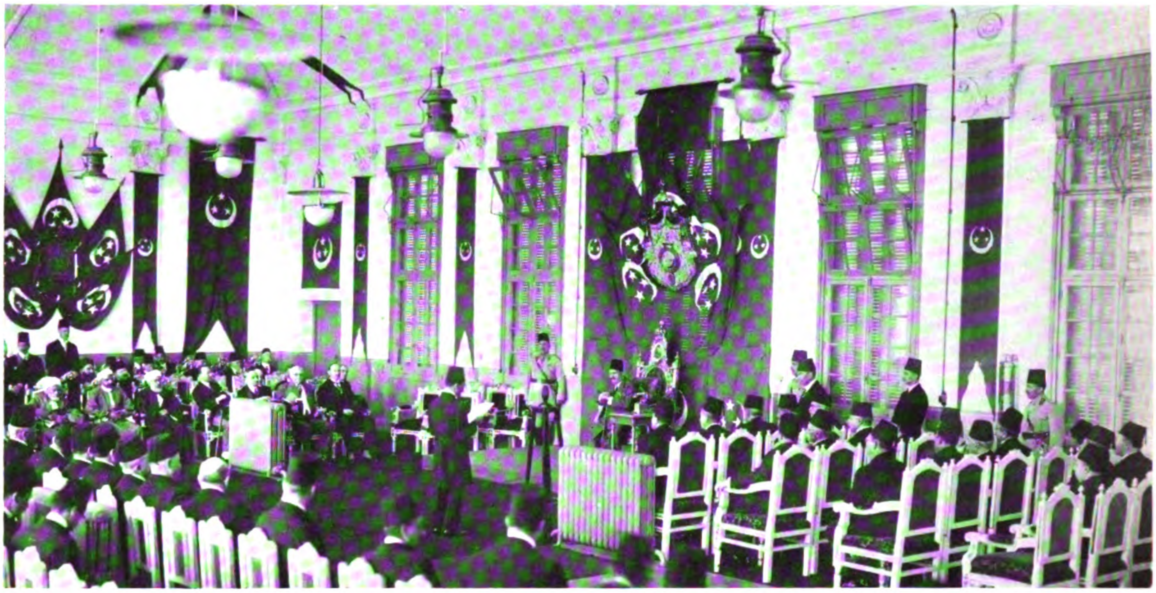

Figure 12—Opening of the Medina (Egyptian Parliament.)

give the broadcasting control engineer instant communication with all strategic points of the system from Brisbane to Adelaide. On the second table is mounted an oscillator and transmission measuring set, used during the preliminary tests for making an overall check of the transmission power levels on the Canberra-Brisbane and Canberra-Adelaide circuits.

The best testimony of the efficient working of the Public Address System is perhaps to be found in its appreciation by enormous crowds—for example, such as listened intently to the running commentary of the football match between Belgium and Holland played recently at Amsterdam (Figure 11). The order and interest displayed by the listeners, prove the effectiveness and value of the system.

Public Address apparatus has penetrated practically to every country in the world. The opening of the Medina, the Egyptian Parliament, is depicted in Figure 12, which shows King Fuad in the Chair being addressed by H.E. Ahmed Khashalia Pasha during the opening ceremony. The peculiar shape of the building made it necessary to place the projectors in the high roof and arrange for eliminating echo effects.

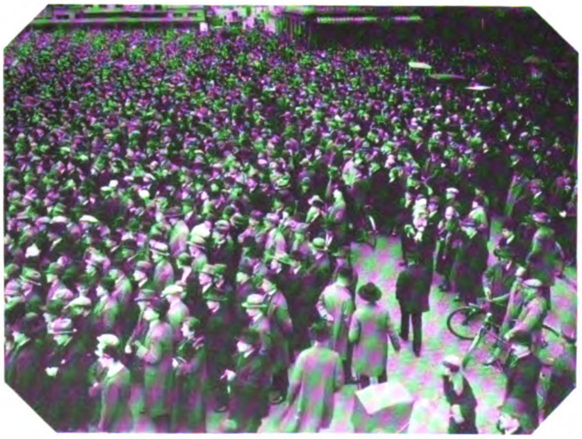

Figure 11—A Section of the Crowd Listening to the Description of a Football Match in Progress Between Belgium and Holland at Amsterdam.

Modern Manual C.B. Switchboards

By A. CAPEK

Bell Telephone Manufacturing Company

Introduction

THE Common Battery manual exchange system was developed during the years of 1892–1898 by the engineers of the Western Electric Company and the American Telephone and Telegraph Company, and was known originally as the No. 1 Relay System.

The success of the No. 1 C.B. board was without parallel in the history of the telephone art; there has never existed and probably never will exist any other type of telephone exchange so widely used for so many years in practically its original form. For about twenty years this board held its prominent place, during which time other competitive systems were developed, tried out and discarded. It was the demand for a more efficient type of exchange for large multi-office areas that put the automatic system in the leading place occupied by the C.B. manual board up to that time.

All of this belongs, of course, to the history of the telephone art. The general introduction of the automatic system has changed entirely the character of the switching problem, and the requirements which manual boards must meet. The automatic exchange system has enjoyed many years of steady progress, as the leading telephone exchange system. The time is opportune, therefore, to review the situation and to see how the spread of automatic operation has affected the position of the C.B. manual system, and what chances for future use are left to it.

The International Standard Electric Corporation, because of its close contact with conditions in all parts of the world, is in a particularly advantageous position to consider the present aspects and future prospects of the C.B. manual system and to determine its sphere of usefulness in the operating field. In this connection it is interesting to recall that the C.B. board with its original 1898 features was considered, during its period of competition with the automatic, as being at the highest point of its development. There also was a time when many competent telephone engineers asserted that the victory of the automatic system would mean the certain death of the C.B. system. Both of these assumptions have proved to be incorrect.

It is obvious that, due to the extended use of the automatic system, the general demand for manual equipment has decreased rapidly; but it is also a fact that there still remains a well defined field of application for C.B. manual boards for isolated plants up to several thousands of lines, where comparative simplicity, low first cost and cheap maintenance are factors of first importance.

The introduction of the automatic type of exchange, on the other hand, has had an excellent effect on the standard C.B. exchange systems. Prior to its advent, manual boards were, of course, improved in some respects and new features, which either simplified the work of the operator or distributed subscribers' calls more efficiently among the different operators, were introduced. Automatic ringing and listening, and the use of auxiliary or ancillary line lamps will serve as examples of such advances. But the radical departure from so-called standard practice only started when it was realized that many of the features of the automatic system, if applied to manual exchange conditions, would also greatly improve the manual service, and increase the operator's loads.

The result of the work in this direction was the development of the so-called high efficiency board (sometimes called superservice board), which will be described later. This improved type of C.B. board, which made it possible to give the subscriber a very much better service, did not, however, entirely eliminate the demand for simple C.B. boards; the manufacturing companies, therefore, were required to make arrangements for furnishing both types; viz., the original C.B. type, and the high efficiency C.B. board.

Preliminary to a somewhat detailed description of the circuit and other features, it is desirable to consider the question of the capacity of the modern C.B. manual board. Formerly it varied from about 300 to about 10,000 lines. C.B. boards under 300 lines were not economical because of the comparatively high cost of the power plant; boards over 10,000 lines required a smaller jack, and, therefore, increased the maintenance cost.

The advent of the automatic system and the later improvements in the manual board changed both of these limits. Present experience indicates that all multi-office areas and single exchange areas likely to require branch offices in the near future are best served by full automatic systems, but for isolated single offices in undeveloped countries up to an ultimate capacity of roughly 5000 lines, there remains a good field for manual C.B. boards.

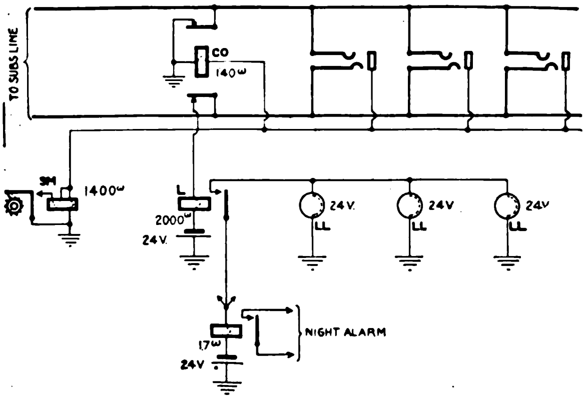

Figure 1—Subscriber Line Circuit.

The more extensive use of portable accumulators, the development of primary batteries of large capacities, and the use of current saving telephone circuits, made it possible to justify economically C.B. boards for exchanges smaller than 300 lines. Small capacity batteries only are necessary, since a manual non-multiple board equipped with a relay condenser cord circuit and subscriber cutoff jacks consumes practically only the current needed for the subscriber transmitters, the current required for signaling purposes (lamps, etc.) being insignificant. On such boards the talking current is comparatively low (with high resistance transmitters, it is 50 milliamperes, or even 20 milliamperes on an average, according to the transmitter and the cord circuit current supply bridge used); and the current consumption for an average 2-minute local conversation is, therefore, but 0.0035 or 0.0015 ampere-hours, respectively. For this reason, even a set of primary cells of 250–500 ampere-hours capacity may satisfactorily supply for several months the necessary current for C.B. exchanges up to 100 or 200 lines.

The restricted field for the C.B. boards, and the smaller capacity of these boards, has also affected the construction of the switchboard section. The standard 3-position section is practically no longer built, being replaced by simple 1-position sections. The latter are more flexible where existing rooms are to be used for housing the exchange and they have the advantage of a cheaper iron construction. Moreover, they are more easily handled in shipment and are preferred to the older types for both the simple C.B. and for the superservice systems. The construction of such boards does not differ very materially from the earlier type of 1-position boards.

With these remarks as an introduction, a more detailed description of both types of manual boards, of their operating features and of the circuits employed to meet the different conditions, will be given.

1. Simple C.B. Manual Boards

This type of switchboard employs the circuits of the old standard No. 1 C.B. board to a limited extent. In case a current-saving arrangement is required, the supervisory relays are equipped with a back contact; and, instead of being shunted as with the No. 1 C.B. board, the supervisory lamps are short-circuited as soon as the supervisory relays operate.

If a condenser-relay transmission bridge is needed, a cord circuit with condensers in both talking leads, and supervisory relays with double windings, may be employed.

For very small boards (non-multiple), the subscriber's line cutoff relay usually is replaced by the cheaper cutoff jack.

A separate intermediate frame may be used but, since the size of the manual exchange is now comparatively small, a combined main and intermediate frame is as a rule preferred.

The operating features and other characteristics common to all such boards are:

1. Repeating coil or relay condenser transmission.

2. Manual listening and ringing.
3. Line relay is cut off from the line as soon as a plug is inserted.
4. Two combined supervisory and clearing out lamps, with positive action, under switchhook control. The lamp associated with the calling plug lights during the ringing period and serves as a guard signal.
5. Capacity busy test, and anti-sidetone induction coil.
6. Pilot lamps for the line signals, but none for supervisory lamps.

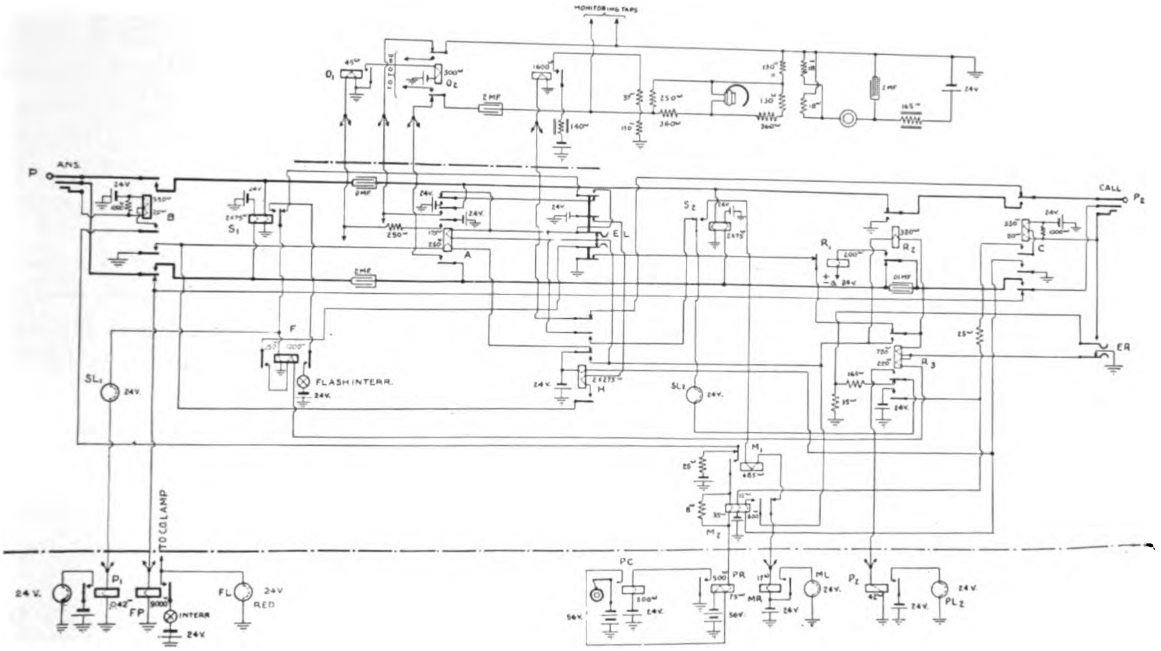

Figure 2—Subscriber Cord Circuit.

The circuits involved are all very well known, and have been used successfully in a very large number of exchanges for a period of nearly thirty years. Both as to operation and service as well as to flexibility, simplicity, low first cost, cheap maintenance and low annual cost, they have proved satisfactory.

2. High Efficiency C.B. Board

Whereas the boards just described, by the retention of practically all of the features common to the No. 1 C.B. system, are designed for a minimum of apparatus and simplicity of circuits compatible with good service; the high efficiency boards, on the other hand, are intended rather to speed up the service by the introduction of features tending to simplify the work of the operator, regardless of the consequent circuit complexity and the larger amount of apparatus involved, the extra initial cost being compensated for by annual charge considerations.

Although the first types of the improved C.B. boards were built in America, the European development of a similar type of board for Europe has had to form the subject of independent study, because the operating requirements, such as those in connection with "toll preference" or the limited demand for measured rate service or party lines and the importance of secret service, are in certain respects radically different from those in the United States.

The questions and problems which must be considered in connection with such a modern C.B. board are numerous. It is, therefore, advisable to investigate all of the operating possibilities systematically for every step of the connection and to note how the different possible solutions satisfy the various demands of telephone administrations. In this manner, it is possible to arrive at the requirements which a high efficiency board has to fulfill.

To investigate in their proper sequence the different problems involved, the whole switching work of the operator will be divided into its elements and each considered separately.

Such elements, for any regular connection, are the following:

(*a*) Calling.
(*b*) Answering, plugging up the calling subscriber, and taking the order.
(*c*) Testing for busy.
(*d*) Connecting to the called line and ringing.
(*e*) Talking, and
(*f*) Clearing out with disconnecting.

There are also the irregular calls:

(*g*) Recalls, and
(*h*) Preference toll calls.

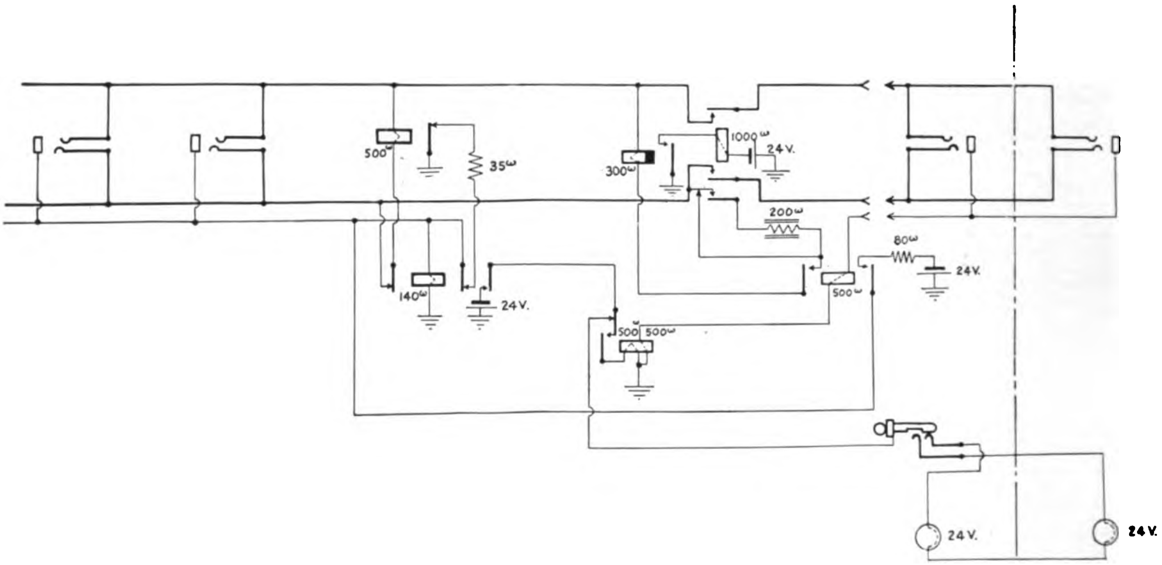

Figure 3—Recording Trunk Circuit.

In addition, there are the different kinds of special services and other features, such as:

(*i*) Subscriber's call metering.
(*j*) Counting the operator's connections (peg count).
(*k*) Party line and coin collect service, and
(*l*) Pilot lamps.

(*a*) *Subscriber Calls:* There are three separate phases which must be considered in connection with this operating element:

(1) The kind of signal used to attract the operator's attention.
(2) The application of busy condition to the calling line.
(3) The arrangement of pilot signals.

(*a*–1) Since the present paper does not deal with automatic distribution, only systems where the subscriber's line ends in a jack and a calling lamp will be considered.

In the standard manual board the line lamp appears as a rule only before one operator, who with her immediate neighbours makes a working team of three. Subscriber lines are as a consequence divided into comparatively small groups and the number of calls arriving at each group varies considerably during any time period.

Different manual schemes were developed to correct the uneven distribution of calls and were put into service, though with more or less success, such as the auxiliary or ancillary answering jacks and lamps, overflow circuits, manual distribution, etc. But of these, the only arrangement which survived was the system with multiple calling lamps. With this scheme, the calling lamps are multipled over the whole exchange and are associated with the multiple jacks, but the usual answering jacks and lamps, together with the answering cable-runs, and the I.D.F., are omitted.

It is interesting to note that this simplest and only practical solution of the distributing problem was the last one to be put on trial. But this may, of course, be accounted for by the unwillingness of telephone engineers to sacrifice valuable multiple jack space for the line lamps. For this reason, the multiple lamp system could only be evaluated after the capacity of manual boards was restricted to 5,000 lines.

The advantages of this multiple lamp system may be summed up as follows:

(*a*–1–1) It is a very efficient system of distribution, as every calling signal is displayed before all operators. In this way a large number of subscriber lines (usually 1,000 or more) can be served in one group having a comparatively uniform flow of calls for any given time interval. Operators serving such uniform traffic can readily handle larger loads than in the normal C.B. system, without increasing the answering time.

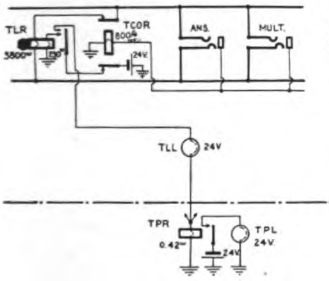

Figure 5—Toll Line Circuit.

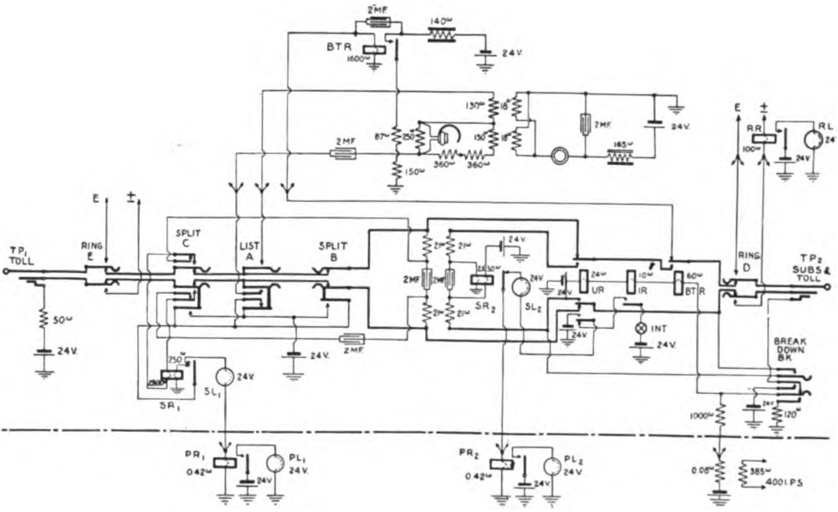

Figure 4—Toll Cord Circuit.

The system permits multiple line lamps to be added through the entire multiple, so that a call is placed before all operators. It is found, however, in practice, that no gain is secured beyond five multiple line lamps—an arrangement which places the call before fifteen operators. The high efficiency exchange of more than fifteen operator positions is, therefore, split up into two or more parts, with the line lamps multiplied in one part only.

(*a*–1–2) The multiple lamp system is very flexible as regards both the normal and abnormal variations of traffic. It makes it possible, therefore, to reduce or to increase the number of operators according to the traffic, without any change or rearrangement of the equipment. Part or full concentration, night service or specially heavy loads, may be easily handled, operators in all cases carrying a full load with standard answering time.

(*a*–1–3) The additional equipment necessary is comparatively inexpensive; the cost of the calling lamps is practically offset by the saving of answering jacks and cables and the intermediate distributing frame.

It is true that the cost of the local cord circuit must be increased to provide means for the first operator who reaches a calling subscriber, to block out any other operator who may have tried to answer the same call. Two marginal relays per cord circuit are needed for this purpose, but these relays serve also for the breakdown of local connections for toll preference.

(*a*–1–4) The increase in operators' load makes it possible to reduce the number of operators for a given traffic. There is consequently a saving in position equipment, multiple sections, floor space and operators' wages.

The drawbacks of the multiple calling line system, compared with its good points, have proved in practice to be only of theoretical significance.

(*a*–1–5) The most conspicuous disadvantage is the reduction of the multiple jack field capacity. It is true also, that the multiple lamp scheme in actual operation is of little value for small boards of less than six operators, but in practice it is potentially useful even for a group of three operators, because a satisfactory size of the group may be reached during the growth of the exchange. On the other hand, groups that are too large would be superfluous; for, teams of more than fifteen operators would not produce any additional equalisation of the load while the additional multiple line lamps would only increase the height of the board and, of course, also its first cost. For this reason the system is limited to exchanges with capacities of 300 to 6,000 lines. Exchanges larger than 3,000 lines are best split into two groups (with a cable box between them). The complete multiple appears in both groups, but multiple lamps are provided in each group only for one-half of the lines.

(*a*–1–6) It might be surmised that the increased load per operator involves an increase in the number of "A" cords, but careful calculations, checked by actual traffic tests, have shown that such is not the case. The uniform load possible with the multiple line lamp, and the large number of operators in one group, increase the connecting efficiency per cord, so that the number of cords per position is the same as in the standard C.B. board. The total number of cord circuits in a high efficiency exchange, due to the smaller number of operators' positions needed, is, of course, less than the total number of cords in a standard C.B. exchange handling the same traffic.

(*a*–1–7) There are two more points which sometimes are brought forward against the multiple lamp system: the greater current consumption due to the multiple lamps, and the duplication of operator's work in case more than one operator attempts to answer a call. Both of these disadvantages are unimportant, as may be seen from the following:

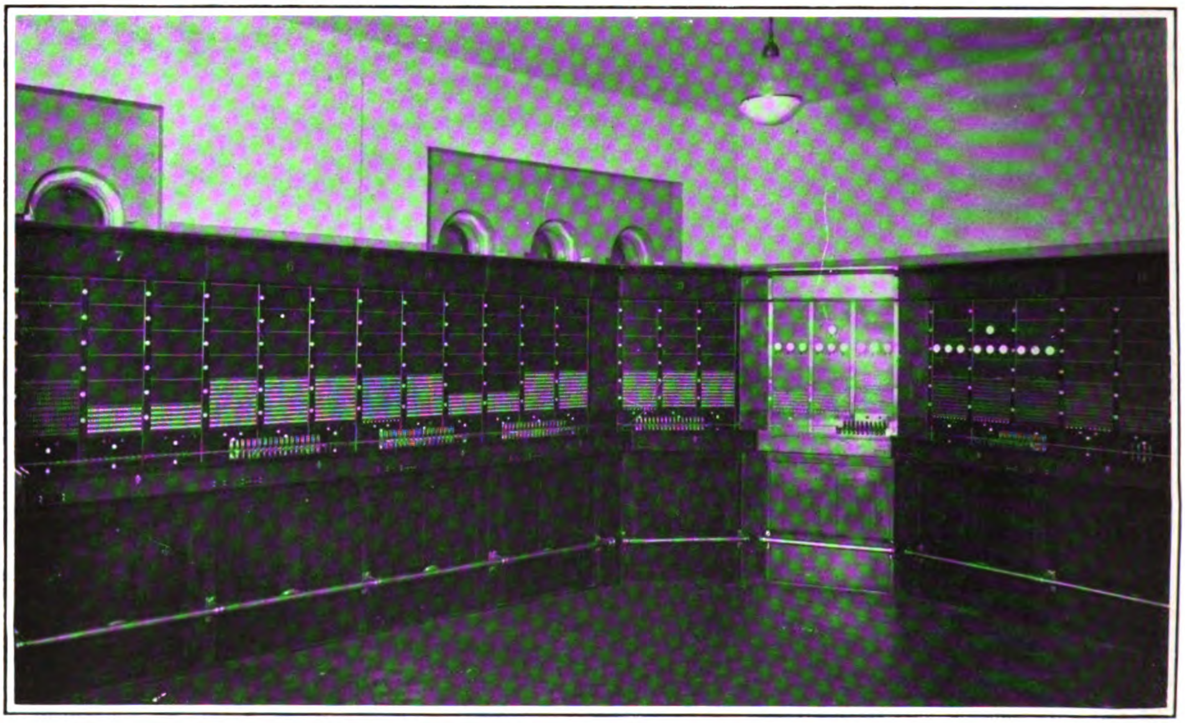
Figure 6—Operating Room—Subscriber boards on the left side, toll boards on the right side.

The line lamp circuit consumption is very small when compared with the total current needed for a conversation. The current for the extra lamps is largely balanced out by the absence of the line pilot lamps, which are no longer needed, and by the shortened time of burning through quicker answering.

The duplication of effort, through attempting to answer a call already picked up, is insignificant when compared with the total work of the operator. It is found in practice that the operator does not actually plug a jack before discovering she is too late. Ordinarily, she notes the line lamp aimed at disappearing and simply picks a neighbouring signal with practically no loss of time. But if she does plug in, she immediately obtains a signal (acoustic or visual, as will be explained later), thus avoiding any further loss of time.

(*a*–1–8) Another objection, which proved largely theoretical, to the multiple lamp system is the point of divided responsibility. It is found in practice that operators inclined to hold back the answering of calls are speeded up by their more industrious colleagues. Furthermore, automatic peg count meters enable the chief operator to compare the operator performance and to locate laggards.

(*a*–2) The next question to be considered in connection with the calling period concerns the application of the busy test to the calling line. The standard manual board makes the calling line busy at the moment when it is plugged up by the answering operator, whereas in the automatic system the calling line is made busy for all incoming calls practically at the moment the subscriber removes his receiver from the hook to make his call. There arises therefore the question whether the latter practice should be adopted also for the high efficiency board.

The delayed application of the busy test has certain disadvantages. In exchanges with a large number of heavily loaded P.B.X. lines and a comparatively low grade of service, it may happen that a P.B.X. subscriber is connected to an incoming call before the answering operator has picked up his line and made it busy. Such connections are particularly annoying, because the P.B.X. subscriber must obtain the attention of his P.B.X. operator— not usually an easy matter—to explain what happened, and to ask her to attend to the new incoming call from the exchange. The results may be even more complicated when two P.B.X. trunks are thus connected. While such connections are rare, they are inevitable with the standard busy test.

Multiple lamps require the operator's bar, and this is secured by arranging for the first answering operator to alter the potential of the test sleeve, so as to make the blocking feature of the other cord circuits connected to the line operative. Such a condition is, of course, contradictory to the simultaneous busy test. The problem is further complicated by the automatic breakdown of local connections for toll preference which must also be effected over the third conductor.

As a result of the considerations mentioned, it was found advisable to retain the busy test method of the No. 1 C.B. board for the high efficiency board. The small disadvantage of such a test is in any case lessened on account of the greatly shortened answering time on the new board.

(*a*–3) The last question to be considered during the calling period is the necessity for the equipment of pilot lamps.

In the multiple line lamp boards the pilot lamps, if provided, would light up during the greater part of the time and, since they serve no useful purpose, they are best omitted.

(*b*) *The operator plugs in and answers:* This period may be divided into the act of plugging up the calling line and the act of connecting the operator's talking set to it. But as in some systems both of these operations are effected simultaneously, it is preferable to consider them both at the same time.

The insertion of the answering plug into the subscriber jack, applies the busy test to the line. At the same time the operator's bar or lock-out must be placed on the line. The cord circuit must be further arranged so that a signal (audible or visual) may be given to another operator who is too late in answering the call.

The operator's bar requires a special relay for every cord, adjusted to distinguish between a busy and a free line, and to connect, or disconnect, the cord circuit apparatus according to circumstances. The connection of the operator's set to the cord circuit may be performed in either of two ways; viz., by means of a key or, automatically, a relay. Automatic or keyless listening saves operating the listening key and requires only one additional relay per cord circuit.

The advantage of "advance plugging" may be considered at this point:

In the standard C.B. boards, the operators are accustomed to plug out a second calling line while answering the first call. In the high efficiency board, the answering time is so short that it seems undesirable to encourage such practice, and the cord circuits should therefore make such "advance plugging" impossible.

(*c*) *Busy Test:* In the design of the high efficiency system, the question of improving the standard C.B. manual click test was given careful consideration. Visual signals were proposed and abandoned. The automatic busy test used in some types of incoming trunk boards presented many advantages. In this, the operater simply plugs in; the apparatus of the cord circuit tests for a free or busy condition of the line, connects in the first case to the calling line and in the second case to a busy tone for the information of the calling subscriber.

The automatic busy test can readily be applied to the high efficiency board, but it was deemed inadvisable for the following reasons:

It would increase the average holding time of cord circuits and therefore also their number because the subscriber is always slower to hang up his receiver in response to a busy tone than if he gets the verbal information from the operator, especially if he also must distinguish other tones, as for example, the ring back tone.

The testing of a P.B.X. trunk group requires manual click testing to find the idle line in the group even when the automatic busy test is employed. The manual click test furthermore allows the subscriber to ask at once for a second number, thereby avoiding delay and saving the operator's time.

It is recommended, therefore, that the standard click busy test be utilized in the high efficiency board.

(*d*) *Connecting to the called line and ringing:* This operating period consists of two independent parts:

(1) The insertion of the plug into the called line jack, an operation which prepares the connection, makes the called line busy and cuts off the operator's set automatically, provided keyless listening is used, and (2) The application of ringing current to the called line and a display of some sort of a ringing guard signal.

The application of the busy test raises the question whether the operator's bar recommended for the answering cord should not be provided also for the calling plug.

This arrangement is not imperative for the calling cord, because it is improbable, except in the case of busy P.B.X. trunks, that a group of operators would try to connect to a line at the same time. For this reason also the boards of American origin are not arranged for such operator's bar, but for the European subscribers this feature is usually specified, the relay required per cord circuit serving also for the automatic breakdown from toll and for secret service. The operator's bar on the calling cord possesses certain operating advantages, in that it prevents double connection, due either to careless operating methods or to simultaneous testing on very busy subscriber lines (P.B.X. trunks).

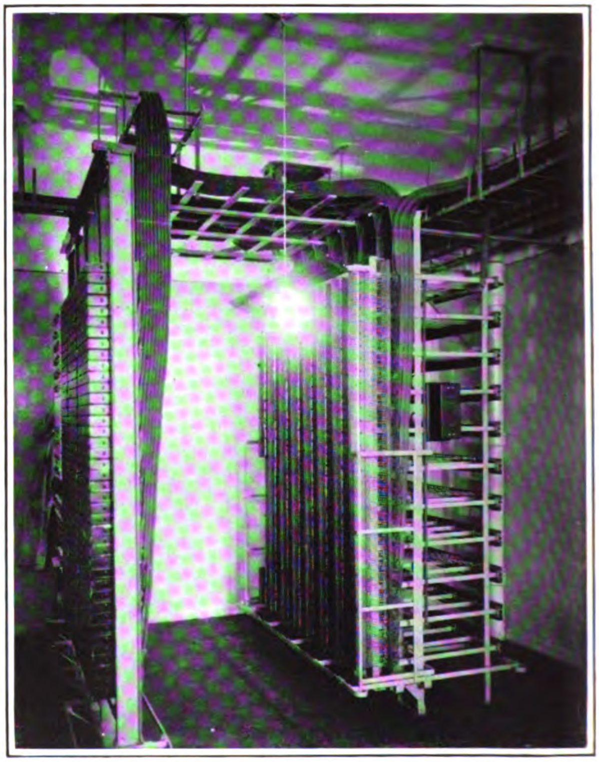

Figure 7—Apparatus Room—Distributing frame with line relay rack (front view).

(*d*–1) As regards ringing on the called line, either manual or automatic types can be provided:

Automatic ringing simplifies the work of the operator, especially during the ringing period. The operator is relieved of all supervision, and does not have to respond to recalls from the calling subscriber for a re-ring. It has been found, in service, that the additional comparatively high cost of this feature (three relays per cord circuit) is justified in all single district offices and in offices with small trunking traffic.

To make automatic ringing successful, it is necessary to give the calling subscriber some sort of a signal during the automatic ringing period, so that he may control the progress of the call, and satisfy himself that the delay in answering is not due to operator carelessness. In case the call is abandoned, it is also important to cut off automatically the ringing current when the calling subscriber replaces his telephone receiver. Furthermore, automatic ringing must be arranged to be cut off the instant the called subscriber takes the receiver off the hook, in order to prevent ringing in the ear of the subscriber, or the sending of ringing current through the transmitter button.

(*d*–2) The ringing guard signal was given much study. In the standard No. 1 C.B. board, the calling supervisory signal remains lighted during the whole ringing period. In European boards of the same type, a ringing pilot lamp is added, as a rule, which lights while the ringing current is sent over the line; that is, during the operation of the ringing key. Such a signal shows the operator that ringing current is flowing, and that the line is not open. In the case of automatic ringing, this problem is somewhat complicated. It is agreed that the operator must know that ringing current is flowing, particularly because the automatic ringing relay may have tripped due to a momentary earth (in the protector, etc.) and disconnected the ringing current. A ringing guard signal, therefore, is required, but it must differ from the clearing out signal. The most economical way to obtain this result is to let the calling supervisory lamp burn dimly during the ringing period, and brightly as a clearing signal. In this way a practically dark keyshelf is obtained, and there is a guard which cannot be misunderstood on the called line. Inasmuch as the additional cost of this arrangement is comparatively very small, it was found advisable to adopt it for all high efficiency boards for Continental use.

(*d*–3) The questions of party line ringing, and the re-ring in case of recalls are discussed hereinafter.

(*e*) For the supply of current to subscribers, only the two very well known types of transmission bridges may be applied: the repeating coil or the condenser-relay arrangement. Both types have certain advantages, so that it is advisable to be prepared to furnish either for the high efficiency board according to local conditions (type of transmitter used, etc.), or the specified requirements.

(*e*–1) The so-called "secrecy" feature, which in a broad sense makes it impossible for the operator to listen-in on a talking connection, has found much favour in Europe, owing to the less efficient supervision in the average European telephone exchange. For this reason all high efficiency Continental boards are arranged for secrecy. This requirement seems to be well defined, but actual experience has shown that there are different grades of it; viz., nominal and actual secrecy.

For nominal secrecy it is sufficient to let the supervisory relays control the connections of the operator set to the cord circuits. But the operators usually discover ways for circumventing this type of secrecy, such as by using a second cord. It, therefore, has been necessary to equip all the high efficiency boards of the European type for "actual secrecy," which makes it practically impossible for the operator to listen-in on a connection.

To secure such secrecy, it is necessary to provide the operator's bar for both cords of a cord pair, and, further, to take particular care that the operator cannot listen by throwing two keys of different circuits (where emergency keys are provided) or by plugging one of the plugs in a dead line.

(*e*–2) There is, however, one eventuality when the operator must enter in on a connection during the talking period, in spite of the secrecy feature, that is, in case of recall or breakdown from the toll exchange, and the circuits of the high efficiency board must be arranged to make this possible.

(*f*) *Clearing out with disconnection:* There are really but two distinct methods of disconnection in manual exchanges: the "manual disconnect," by taking down the cords, and the "automatic disconnect," in which the talking conductors of the cord are automatically opened, when the subscriber restores his receiver. In the manual method, the subscriber's line remains busy until the operator takes down the cords. In the automatic method, the line is made free as soon as the subscriber hangs up his receiver; in other words, the subscriber who originated the call (or exceptionally also the called subscriber) controls the connection.

In the manual disconnect, the recall signal appears on the cord circuit used for the connection, so that the original operator, who answered the call, also handles all "recalls." In the automatic system, a recall will appear on the multiple line lamps as a new call, with the probability that another operator, who knows nothing about the original call, may pick it up.

The shorter time during which the calling subscriber's line is kept busy, is certainly an advantage of the automatic disconnection, but this "line lamp recall" feature also has its drawbacks. In case a manual subscriber flashes the operator (because he has received a wrong number or because he wants her to ring up his party again, or in case he has moved his switch-hook by mistake), it is advisable that the recall should be handled by the original operator who can deal with it intelligently and promptly. Furthermore, a new operator would not always be able to attend to a recall (for example, if the subscriber should request his party to be rung again, in case of operator's bar on both cords) and would have to wait until the original connection was taken down.

Another difficulty is encountered with the automatic type of disconnection, in case a measured rate subscriber gets a wrong number, either due to his own or to the operator's fault; here again, only the operator who originally attended to the first call can properly take care of it and meter it correctly.

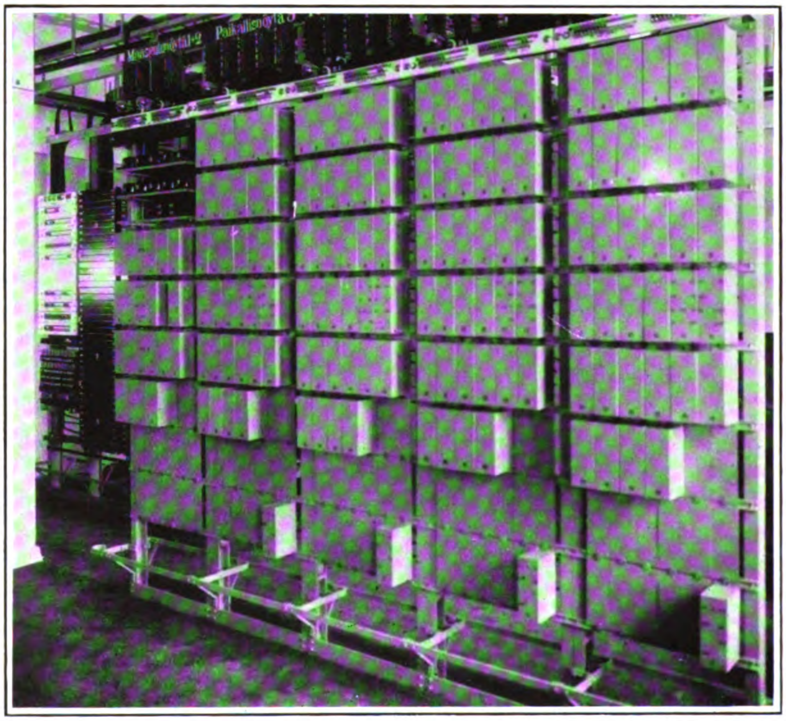

Figure 8—Apparatus Room—Cord circuit relay rack with fuse panel (front view).

It is true, of course, that in automatic exchanges no difficulty is encountered in a similar case, but it must be remembered that the general feeling of subscribers in a manual system is entirely different from that of subscribers in an automatic system. A subscriber in a manual system, in general, tends to attribute mistakes to the operator whereas the subscriber in an automatic system usually is quite certain that calls that go wrong are due to his own mistakes.

From the preceding, it is apparent that the automatic disconnecting system may be considered advantageous only from the viewpoint of making the calling line free more quickly, and that in all other respects, the manual disconnecting system is superior, especially where a double-sided operator's bar is specified and where the calls are metered. It is, therefore, preferable to arrange the high efficiency board in Europe for manual disconnecting, and to consider the automatic disconnecting system in special cases only where subscriber message registers are not employed.

(*g*) *Recall:* The usual type of recall in connection with the manual disconnection system, that is, the flashing of the supervisory lamp in accordance with the movement of the subscriber's hook, is not a very efficient way of gaining the operator's attention, as the operator may easily overlook it when she is very busy, because of the absence of any special signal after the flashing period and because the signal may be indistinct in case the subscriber moves the switchhook very quickly. For these reasons it is advantageous to make the flashing recall positive and visible. It should be set by operating the switchhook once, and maintained until the operator answers. Such an "automatic flashing recall" signal as a rule is applied only to the answering cord, where recalls usually occur (up to 10 per cent of the total calls against 1 per cent from the called subscriber).

In the case of an inadvertent movement of the switchhook, the automatic flashing recall will, of course, make it necessary for the operator to enter in the connection. The number of such false calls is, however, extremely small.

The recall requirement may, of course, clash with the secrecy feature; the operator in response to a recall, therefore, must be in a position to break down the secrecy, as it may happen that the second party may remain at the telephone.

The simplest solution would be to let the operator remove the calling plug, and get automatically in connection with the calling line. This procedure is admissible, as the operator must remove this plug in most cases of recall. If, however, the called subscriber remains at his telephone, this act would display a false line signal along the board. To prevent such a false call, the operator preferably removes the answering plug and replugs with the answering plug of an idle pair. Very often it is deemed necessary to install special emergency listening keys for this purpose, but such equipment is, of course, optional.

(*h*) *Toll calls for local busy subscribers* (*preference toll calls*)*:* There are three different ways of handling incoming toll calls for subscribers who are engaged locally. The toll operator waits until the subscribers' line is free (American method), breaks the local connection in preference for toll (European Continental method), or first offers the toll call to the subscriber talking locally, and the local connection is broken only if the subscriber agrees to accept it (English method).

The European telephone administrations usually employ the second (breakdown) operating method, for the reason that the number of toll lines available is very limited and it is, therefore, necessary to employ all possible means to improve their efficiency.

The standard C.B. system provides for this toll preference service in several ways, the most expensive arrangement consisting of a cutoff jack (or a parallel jack with a cutoff relay) for every subscriber line in the toll switching section. This switching method was formerly very popular in Europe, as it was possible to break positively the local connection at any time and also to disconnect the switchboard multiple cabling from the toll connection.

Another solution of this problem is to use parallel multiple jacks in the toll switching section, in connection with switching trunks which are arranged to permit the toll operator to flash the supervisory lamp of the local cord, making the line "locally busy," thus giving a peremptory disconnect signal to the local operator. With this arrangement the toll operator is, of course, dependent on the local operator for a prompt response.

The high efficiency boards possessing the operator's bar are particularly well adapted for toll preference connections, because relays needed for non-interfering answering can be used also for disconnecting the local cord circuit from the subscriber line which is required from the toll board. This toll breakdown feature is, of course, needed both for the answering and the calling cords; and to get the full value of it, it is recommended that the following additional operating features be added:

(*h*–1) The breakdown of the local connection should remain under the control of the toll operator, so that the toll operator may prepare the complete toll connection and open the local cord only when she is ready.

(*h*–2) During the waiting time, a guard signal should be displayed, which reminds the toll operator that she has a connection under preparation.

(*h*–3) The local operator must be notified in case of a toll breakdown; preferably by means of a flashing supervisory lamp signal on the particular cord which was cut off so that the other subscriber (not required for toll) may be informed of the "cut off for toll."

(*h*–4) The action of cutting off the local cord circuit must, of course, not connect the particular local operator set to the interrupted cord circuit, but the local operator must be able to get in on the connection—either by means of an emergency listening key, if such is provided—or simply by withdrawing the plug, which was just disconnected.

(*h*–5) The toll operator should be prevented from ringing up by mistake a subscriber who is talking locally.

It is, of course, understood that this operating condition must apply either to toll boards equipped with subscribers' multiple jacks and also to toll boards, where the subscribers' lines may be reached over toll switching trunks.

The circuits arranged for automatic breakdown of local connections for toll calls, may be, of course, used without further change for the operating method of "offered" toll calls. In this case a special additional cord is needed—arranged so that the insertion of the particular plug into the locally busy subscribers' line does not change its electrical conditions. If the subscriber accepts the toll call, the special plug is removed, and replaced by the regular toll cord equipped for toll breakdown.

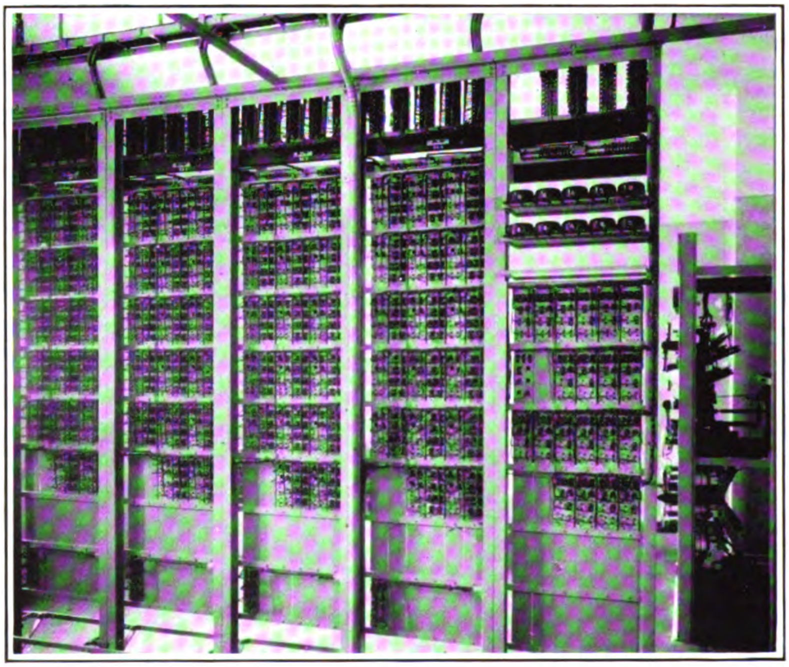

Figure 9—Apparatus Room—Cord circuit relay rack (rear view).

(*i*) *Subscribers' call metering:* The policy of introducing message rates varies widely; the different countries and subscribers cannot be classified definitely as flat rate or message rate subscribers, because flat rate subscribers, within a short time, may be operated on a message rate basis.

The high efficiency boards of the European type must, therefore, be made suitable for subscribers' message registers even if it is not necessary to equip them. In the standard manual board, these registers are operated, as a rule, manually. The experience with message registers in automatic exchanges has shown that it is possible to do the metering automatically, with very satisfactory results. There is no good reason why automatic registration could not be introduced in a high efficiency board, especially where such a board is arranged for automatic flashing recall.

Automatic message registration must, of course, be designed to omit the metering of service calls to recording or information desk, and must permit the operator to suppress a call, in case of a wrong number. An alarm signal should be provided to operate in case the register does not meter properly.

(*j*) *Operator's peg count* (Position meter): Multiple line lamps shorten the answering time, but the full benefit is only secured if all operators cooperate. To this end, a peg count should be provided for every position, as a check for the operators. This meter must be arranged to count automatically either all the connections completed or all calls answered, or both.

Such a peg count for checking the work of the operators must be automatic and beyond interference by the operator. It is not very easy to fulfill this condition for the peg count for answered calls, as this meter is controlled by one supervisory relay only; it is advisable to use or to add a peg count meter for effective (or completed) connections, as this type of meter operates only if both supervisory relays are energized. Such an arrangement offers, in connection with non-interfering answering, a very efficient method for preventing any incorrect manipulation of the meter. As the number of answered calls bears a certain relation to the number of effective calls for every exchange, it is a comparatively simple matter to check, in this way, both peg count figures.

(*k*) *Party line and coin collector service:*

(*k*–1) Party line operation is not very popular in Europe, owing to the lack of secrecy, and to the fact that the additional cost involved in correcting this deficiency makes it uneconomical. It is, therefore, entirely satisfactory to omit party line equipment from the standard high efficiency boards and, in every special case where it is required, to adapt the line and cord circuits to the particular kind of party lines in use.

In connection with the question of party line equipment, there are two points to be kept in mind:

(*k*–1–1) Owing to the multiple line lamps used in the superservice board, it is not feasible to use one multiple jack lead for every party line station with the usual type of party line sets, and it is, therefore, necessary to provide special ringing keys (common or individual) in the cord circuit, for this service.

(*k*–1–2) In the standard C.B. board, where a separate answering jack is provided in addition to the multiple jack, the operator's position is arranged for a special "revertive busy test" connected to the third wire of the calling line while the listening key is thrown, so that the operator may hear this special tone when testing, and recognise it as a case of a revertive call. In case of multiple line lamps, the revertive busy test is not needed, because the operator quickly discovers that the number requested is the one she has just answered. On such revertive calls the operator will, therefore, first ask the calling station to hang up the receiver for a short time; she will then remove the answering plug, insert the calling plug and ring the called station by depressing the proper ringing key.

(*k*–1–3) For the different types of coin collectors, different arrangements in the line or in the cord circuits are necessary, and can be provided in any type of high efficiency board. As, however, the coin collecting service is only a special kind of message rate service, it is understood, of course, that only the automatic flashing recall cord circuits should be used in connection with it.

(*l*) *Pilot lamps:* As previously explained, pilot lamps in connection with the multiple line lamps are best omitted, but pilot lamps for clearing-out signals are to be recommended. Such lamps were never provided in the standard No. 1 C.B. board, because the additional apparatus required was found to be more considerable than the resultant improvement in service would economically justify.

In the high efficiency board, it is comparatively simple and inexpensive to provide pilots for the supervisory lamps which will light only when the supervisory signals are displayed, thus reinforcing the clearing out signal and speeding up the disconnection service.

These pilot lamps should be located in the piling rail, together with other alarm lamps needed in the cord circuits, so that the attention of the operator may be solely concentrated on the face of the switchboard, totally disregarding the keyshelf signals, except when removing cord pairs.

SUMMARY OF HIGH EFFICIENCY BOARD FEATURES

In the preceding pages, the reason why certain features of the automatic system could, or could not, be applied with advantage to a modern C.B. board has been explained and, furthermore, why certain features peculiar to the manual system were recommended or rejected as unsuitable.

The features accepted are summarized as follows:

(*a*) *As regards construction.*

(*a*–1) Sections of the one-position type.

(*a*–2) Capacity up to about 6,000 lines with no space for answering jacks.

(*a*–3) No intermediate distributing frame.

(*b*) *As regards operation.*

(*b*–1) Multiple line lamps (maximum 5 lamps).

(*b*–2) No line pilot lamps.

(*b*–3) Calling line made busy by insertion of answering plug.

(*b*–4) Operator's bar for both answering and calling cords.

(*b*–5) Alarm signal in case operator plugs into a busy line.

(*b*–6) Automatic (keyless) listening (cut in and cut off).

(*b*–7) "Advance plugging" made impossible.

(*b*–8) Manual busy test.

(*b*–9) Automatic (keyless) and clickless ringing.

(*b*–10) Ringing-back tone to calling subscriber (audible ringing).

(*b*–11) Automatic disconnection of ringing current on called subscriber answering or on abandoned calls (ringing controlled by calling subscriber).

(*b*–12) Ringing guard signal during the ringing period.

(*b*–13) Repeating coil or relay-condenser talking current supply.

(*b*–14) Absolute secrecy while both subscribers are talking.

(*b*–15) Two positive clearing out lamps.

(*b*–16) Clearing out pilot lamps (2).

(*b*–17) Automatic flashing recall (for answering cords only), with

(*b*–18) Emergency listening and ringing keys (optional), or with

(*b*–19) Removal of the calling plug on recall before talking.

(*b*–20) Recall on calling supervisory lamp without automatic flashing (answered by operating emergency listening key or by withdrawing the answering cord).

(*b*–21) Automatic disconnecting (line lamp flashing recall) for answering cord only if no subscribers' meters are equipped (optional).

(*b*–22) Toll operator may break down a local connection at any time (by means of a key).

(*b*–23) In the interval between plugging into the subscribers' line and breaking the connection, a guard lamp to advise toll operator.

(*b*–24) The local operator to receive a special peremptory signal in case of a toll breakdown.

(*b*–25) The local operator to be able to talk to the subscriber in case of a toll breakdown (by means of emergency key or by withdrawing one plug).

(*b*–26) Toll operator not to be able to ring on a line after breakdown.

(*b*–27) Automatic subscribers' message registration with discrimination.

(*b*–28) Operator to be able to suppress metering.

(*b*–29) Subscribers' meter cuts off the cord circuit only after it has registered.

(*b*–30) Alarm signal displayed if meter does not register properly.

(*b*–31) Peg counts for completed (effective) connections, also peg counts for answered calls (optional).

(*b*–32) Coin collect keys (collecting and returning) (only if required and only in connection with automatic flashing recall circuits).

(*b*–33) Party line ringing keys (only if required).

Various cord circuits may be developed to satisfy these requirements, the line circuit remaining practically unchanged (Figure 1). A typical cord circuit (Figure 2), which is working satisfactorily in actual service, will be described briefly in connection with other associated circuits (toll and recording, Figures 3 to 5).

The connecting cords as shown are equipped with emergency listening and ringing keys (*EL* and *ER*), but party line or coin collecting keys are not provided in this case.

The relay condenser talking battery bridge consists of two supervisory relays (S_1 and S_2) with two supervisory lamps (SL_1 and SL_2). There also are provided: an operator bar relay per cord (*B* and *C*), three relays (R_1, R_2 and R_3) for the automatic ringing, one relay *A* for automatic listening, one relay *F* for the automatic flashing recall, two relays (M_1 and M_2) for the automatic subscribers' metering and peg count, and one helping out relay *H* (total twelve).

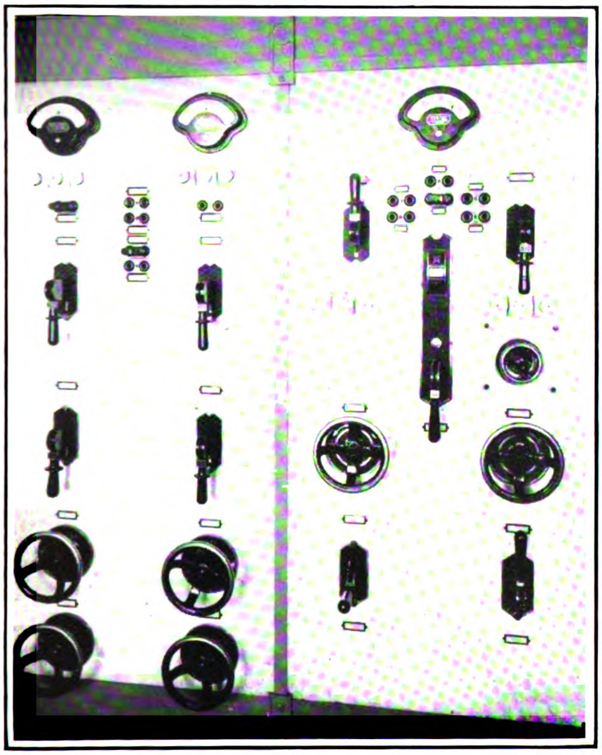

Figure 10—Power Board.

The common equipment consists of a peg count meter *PC* with an associated relay *PR*, of an alarm lamp *ML* with relay *MR* (for out of order subscriber registers), an alarm lamp *FL* with relay *FP* as operator bar signals, and of two operators lock-out relays O_1 and O_2 for cutting off the operator's circuit in case she tries to evade the secrecy restriction by using two pairs of cords.

Operation of Circuits (Figures 1 and 2)

A detailed description of every step of the operation does not seem necessary, so that it seems sufficient to indicate what relays and lamps operate in any working period. The letter references for such apparatus in general will be included in brackets.

(*a*) *Regular local connection*

(*a*–1) Subscriber takes his receiver from hook, *L* operates—*LL* lights (*L.LL*).

(*a*–2) Operator plugs in (with P_1) and takes order: the marginal relay *B* pulls up (over both windings in series), locks over its low resistance winding, and places in this way a low resistance shunt parallel to its high resistance winding. The B. or C. relay of any other cord of the switchboard cannot be operated in case its plug is inserted in a multiple jack of the same line.

Relays *CO*, S_1 and *A* operate: the operator set is connected automatically to the calling line. But the subscriber meter *SM*, and also relay O_1, do not operate in this case (both being marginal) ($A.B.S_1.CO$).

(*a*–3) Operator tests a non-busy line (capacity busy test) ($A.B.S_1.CO$).

(*a*–4) Operator plugs into the called line and automatically connects ringing current to it. Relay *C* energises in a similar way as described for relay *B* "operator's bar." Relay *H* is energised, then relay R_2. "*A*" relay and the operator's set are disconnected, and the ringing trip relay (R_1) is connected to the calling subscriber line. Interrupted ringing current (exchange battery current during the silent period) is sent over the called line, and a small part of it over a 0.01 *MF* condenser back to the calling subscriber (ring-back signal). During the ringing period the supervisory lamp SL_2 lights dimly (over 165 ohms and 35 ohms resistance) as a guard signal ($B.C.S_1$ both $CO.R_2.H.SL_2$).

(*a*–5) Called subscriber answers: Relay R_1 is adjusted in such a way that it does not pull up with ringing current over the condenser of the subscriber set. When the subscriber takes his receiver off the hook and closes a direct current path over his transmitter, relay R_1 pulls up (either on ringing current or on direct current during the silent period) and opens the short circuit across relay R_3. The latter operates, releases R_2 and disconnects R_1 from the subscriber line. The circuit of the supervisory relay S_2 is now closed and operates relay M_1 for a moment (over pilot relay P_2) connecting thus the 56 volt meter battery over the common relay PR and over relay M_2 to the sleeve wire of the calling line. Relay PR pulls up and closes the circuits of the peg count PC (which operates once), but the relay M_2 as well as the subscriber's meter do not operate yet, owing to the high resistance of the two windings of relay PR. It is only after both the peg count and the subscriber's meter have registered, that is, after low resistance shunts are placed across the high resistance windings of the relay PR and across the meter SM, that the relay M_2 pulls up and cuts M_1 from the meter battery. Relays PR and M_1 release, both peg count as well as subscriber's meters are energised, and relay M_2 remains locked ($B.C.S_1.S_2$ both $CO.R_3.H.M_2$).

(*a*–6) Both subscribers talk: The operator is not able to listen to the conversation. The throwing of the emergency key EL remains ineffective ($B.C.S_1.S_2$ both $CO.R_3.H.M_2$).

(*a*–7) Both subscribers hang up: Both supervisory relays (S_1 and S_2) release, lamps SL_1 and SL_2 light up (clearing out signal), relays P_1 and P_2 operate and pilot lamps (PL_1 and PL_2) light up ($B.C.SL_1.SL_2$ both $CO.R_3H.F.P_1.P_2.PL_1$ and PL_2).

(*a*–8) Operator removes cords: All apparatus is deenergised and returns to normal.

(*b*) *Other local connections* (*including irregular*)

(*b*–1) Operator tries to answer a call already answered by another operator. The marginal relay B does not pull up in this case, but the common relay FP operates, and FL lamp flashes so as to give the operator a warning signal. The second operator cannot disturb the existing connection in any way, because the cord used remains disconnected from any cord apparatus. The emergency key EL when operated does not change the conditions ($FL.FP$).

(*b*–2) The operator plugs into a busy line with her calling plug—trying to complete a connection—by mistake or as a result of a simultaneous test. The marginal relay C does not pull up but relay FP energises and lamp flashes ($A.B.S_1.CO.FP.FL$).

(*b*–3) Calling subscriber abandons call during the ringing period (called subscriber does not answer): During the ringing period the following relays are energised and lamps burn:

$$B.C.S_1 \text{ both } CO.R_2.H.SL_2.$$

If the calling subscriber hangs his receiver up, the relay S_1 releases, clearing out lamp SL_1 and the pilot lamp PL_1 light up. Relay F pulls up, causing relay R_3 to operate, which releases R_2, disconnecting ringing current from the line. The operation of R_3 puts full potential on the lamp SL_2, which lights brightly (as does the pilot lamp PL_2) so that the operator gets a regular double clearing-out signal, and may disconnect ($B.C.$ both $CO.R_3.H.F.SL_1.SL_2.P_1.P_2.PL_1.PL_2$).

(*b*–4) Operator tries to evade secrecy: It was explained under (*a*–6) that the circuit is arranged in such a way that the operator cannot listen on a talking connection by simply throwing the emergency listening key.

In case the operator tries to get past the secrecy feature by using two pairs of cords, for example connecting by means of two answering cords (after ringing up the called subscriber in the regular way), she will not succeed, because only one of the A relays operates. The apparatus energised in the first cord circuit is:

$$CO.B.S_1.H.SL_2 \text{ (dim.)}$$

and in the second cord circuit:

$$CO.\mathrm{B}.S_1.A.$$

If the operator should now try to listen by also throwing the emergency listening key (or keys), she will release relay H of the first cord used, and thus energise the second A relay. But this now increases the current in the common relay O_1 so that it operates, and energises relay O_2 which in turn connects a buzzer tone to the operator's set.

Apparatus energised in both cord circuits are: $CO.B.S_1.A$ in addition to the common relays O_1 and O_2.

(*b*–5) Calling subscriber flashes his supervisory lamp, after the called subscriber has hung up his receiver (recall).

Before the calling subscriber moves his switchhook, the following apparatus is energised (see *a*–6 and *a*–7):

$B.C.S_1.SL_2$ both $CO.R_3H.P_2.PL_2.H_2$.

If the calling subscriber opens his line by depressing the switchhook, the relay S_1 releases, SL_1 lights (with pilot lamp PL_1) and F pulls up and locks over its 1,200 ohm winding. As soon as the calling subscriber closes his line again, relay S_1 energises and SL_1 lamp starts to flash regularly as does the pilot lamp PL_1. Further movements of the subscriber switchhook do not influence this automatic flashing signal and the operator is now able to talk to the calling subscriber, by throwing key *EL*, which energises relay A (over lamp SL_2) and releases relay F. The operator may now remove the calling plug (with *EL* thrown), thus causing the release of relays $C.H.R_3$ with M_2 and stopping lamp *SL* (with PL_1) from flashing.

In case a second connection is wanted, the operator will test and plug in, and the new connection will be completed as described under (*a*–4) and (*a*–5). If a wrong number is to be corrected and the new connection is not to be charged to the calling subscriber, the operator may prevent the second metering by throwing re-ring key *ER* after the insertion of the calling plug. Such action will put a 35 ohm shunt across the 140 ohm winding of the cutoff relay of the called subscriber line, and will energise relay M_2 (marginal) over its 12 ohm winding, thus preventing M_1 from operating later when the called subscriber answers.

In case the calling subscriber flashes and wants to re-ring his party—who abandoned the call or hung up by mistake—the operation is the same as just described, but it is, of course, not necessary to remove the calling plug. The operator will simply throw the re-ring key *ER* for a moment, and thus cause the release of relay R_3, energise R_2 and place the ringing current on the line again. The meter relay M_2 remains locked during this operation, so that a second registration is prevented.

(*b*–6) If, after the conversation, the calling subscriber hangs up, but the called subscriber flashes the operator, the lamp SL_2 will follow the movements of the switchhook in the same way as in the standard manual board, and the operator may now talk to this subscriber by throwing the *EL* key, as this movement energises relay A (over the back contact of the supervisory relay S_1). If the called subscriber wants a new connection, the operator will remove the called plug, insert answering plug and complete the connection as described.

(*b*–7) If the calling subscriber desires a connection which should not be metered, such as a recording or desk line, the particular line circuit (recording trunk, etc.) must be arranged in such a way that the meter relay M_2 energises over the 12 ohm winding (and locks) as soon as the calling plug is inserted, and prevents registering later on when the desk operator answers and the supervisory relay S_2 is operated. Such a trunk circuit (Figure 3) must be equipped for this purpose with a low resistance shunt across the 140 ohm cutoff relay, and this shunt must be disconnected only after the M_2 relay is energised.

(*b*–8) Toll operator breaks a local conversation: It is understood that the toll boards used in connection with superservice boards, in the majority of cases are equipped with subscriber multiple jacks because of the comparatively small size of such boards. The toll cord circuit provided for such boards (Figure 6), is, therefore, of the so-called semi-universal type; that is, of a type arranged for connecting a toll line to another toll line or to a C.B. subscribers' line, but not adapted for connecting two C.B. lines together.

In case the toll board is not equipped with subscriber multiple, the toll operator must secure the local subscriber over a separate toll switching trunk ending in a plug before an operator at the local board. It, however, seems sufficient to describe the toll breakdown feature in connection with the semi-universal toll circuits.

The toll cord, as shown in Figure 4, is equipped with the usual ringing, listening and splitting keys, supervisory and clearing-out relays, repeating coil, busy test relay *BTR* and switching relay *UR*, and also with a breakdown key *BK*, and the IR-relay used for the operation of the toll supervisory guard lamp flashing.

(b–8–1) In case the toll operator desires to break the local connection from the answering side of the local cord circuit during the conversation, it will be recalled that relays $B.C.S_1.S_2.H.R_3.M_2$ of the local cord circuit and both CO relays of the line circuit are energised during this period.

(b–8–2) The toll operator inserts plug TP_2 in the subscriber's jack in question (after testing for busy).

The act of plugging of TP_2 operates the busy test relay BTR (which cuts off the busy test winding of the operator's induction coil) and the flashing relay IR, which flashes the supervisory lamp SL_2 and PL_2 (guard signal for operator). The marginal relay UR does not operate. At the same time, a special tone test is placed on the third wire of the subscriber's line, to make it "toll busy" ($B.C.S_1.S_2.H.R_3.M_2$. both CO_2 – $BTR.IR$ and SL_2 with PR_2 and PL_2 flashing).

(b–8–3) The toll operator over the listening key A informs the subscriber talking locally that he is required for toll connection, and that his local conversation will be interrupted (at once or later—according to the progress of the toll connection). The condition of the apparatus remains otherwise unchanged.

(b–8–4) The toll operator breaks the local conversation, when she is ready, by operating the breakdown key BK. This action places the full 24 V. battery potential on the sleeve wire of the subscriber's line in question; the B relay of the local cord is now short-circuited, drops back and releases, and with it the supervisory relay S_1; lamp SL_1 lights up as does the pilot lamp PL_1. At the same time, the marginal relay UR pulls up and with it relay SR_2, disconnecting lamp SL_2 ($C.S_2.H.R_3.M_2.F.SL_1.P_1.PL_1.$ – $BTR.IR.UR.SR_2$).

(b–8–5) When the toll operator releases the BK key, the marginal relay UR remains energised (over the subscriber's cutoff relay) and prevents a new operation of the B relay of the local cord circuit just released, because the high winding of the B relay is shunted out by the combined resistance of the windings of the relays $UR.IR$ and BTR. The operation of UR disconnects the flashing signal of SL_2, places the talking bridge on the subscriber line and supplies at the same time battery for the common flashing relay FP in the local cord circuit. This relay, therefore, pulls up and closes the circuit of FL over an interrupter. This causes lamp FL to flash and it gives a peremptory disconnect signal to the local operator ($C.S_2.H.R_3.M_2.F.SL_1.P_1.PL_1.FP.FL.$ both $CO.BTR.IR.UR.SR_2$).

(b–8–6) In case the second locally connected subscriber, whose party was just taken away for a toll call, did not hang up his receiver promptly as directed by the toll operator, the local operator may talk to him after operating the emergency listening key EL, thus again energising relay A.

(b–8–7) The toll operator may break down the local connection from the calling side of the local cord circuit, in which case the operation of the circuits involved is similar to that just described. She also may break down from either side of the local cord during the answering or during the ringing period with the same result, that is, relay B with S_1 or relay C with S_2 are released, lamps SL_1 or SL_2 light and lamp FL flashes.

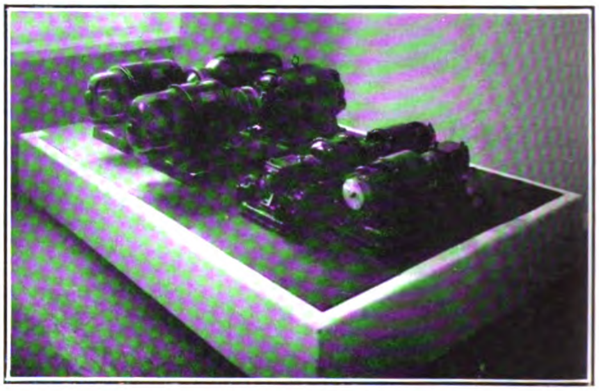

Figure 11—Charging Set and Ringing Machine.

It has only to be remembered, in case the toll operator requires a subscriber who is just being rung on some local position, that a signal will be displayed on the toll position upon inserting plug TP_2 in the multiple jack, because relay SR_1 will operate from the ringing current sent from the local cord and lamp SL_1 (with RPL_1) will light. The toll operator in this case will not throw the listening key A, because she would get ringing current in her receiver, but will break down the local connection immediately by operating the *BK*-key. The ringing relay of the local cord circuit then will trip over one winding of the SR_2 relay of the toll cord and the operation of the circuits thereafter will be the same as described previously.

CURRENT CONSUMPTION OF THE HIGH EFFICIENCY CIRCUITS (FIGURES 1 AND 2)

The current consumption of the high efficiency board is far less than might be supposed. It will suffice to make a comparison of the current needed for apparatus operation with that of the standard No. 1 C.B. system, and to disregard for the moment the current necessary for transmission purposes, inasmuch as this current may be assumed to be the same in both systems, even if the transmission bridge, shown in Figure 2, is different from the bridge of the No. 1 C.B. board.

For comparison it furthermore suffices to consider the amount of the signaling current needed during the talking period only, because current flowing before and after the talking period is of short duration and negligible.

In case of the No. 1 C.B. board, there is but the current flowing over the third wire amounting to 0.32 ampere (2 × 0.16 ampere).

The current flowing during a connection on a high efficiency board of the type shown in Figures 1 and 2 is as follows:

For two sleeve wires:	0.26 ampere (2 × 0.13 ampere)
For relay *II*:	0.09 ampere
For relay R_3:	0.03 ampere
For relay M_2:	0.04 ampere

or a total of 0.42 ampere, which is only about one-third more than the current consumed in the No. 1 C.B. board.

Adding now an average solid back type transmitter current of the repeating coil type cord circuit of say 0.2 ampere (2 × 0.1 ampere) to both figures, the total current consumed in the high efficiency board is but 0.62 ampere as compared with 0.52 ampere in the No. 1 C.B. board. This small increase in the cost of power supply affects but very little the total annual operating cost.

OPERATORS LOAD ON THE HIGH EFFICIENCY BOARD

The number of busy hour connections which may be handled on the high efficiency board is a very important factor, inasmuch as its economic success depends largely upon this figure.

The operator can certainly answer more calls on such a board than on a standard C.B. board, owing to its labour saving and call distributing features, but the figures found or claimed in actual service vary from 300 to 500 and even 600 calls in the busy hour.

It will be interesting to see what saving in the operator's time may be reasonably expected on a high efficiency board and to determine the operator's time needed for a connection. By comparing this figure with the operator's time and with the basic busy hour load of a No. 1 C.B. board, it is possible to arrive at a fairly accurate busy hour load for the new board.

For the smaller C.B. manual boards, with an average of about ten to fifteen positions, the basic operator busy hour load is generally taken as 230 flat rate calls. For message rate calls this figure is reduced by 5 percent (to 218 calls) if key registering is used.

It is assumed that the operator spends an average of about 7½ seconds on a connection in the standard C.B. manual board under favourable conditions and "overlapping operations." For European conditions it is safer to consider 8 seconds per connection.

To this must be added the time spent for such irregular service as cannot be considered and charged up as a call; for example, correction of wrong numbers, re-rings, etc., say: 0.5 to 2 seconds according to the different countries, making a total of 8.5 to 10 seconds.

For key metering, the operator's time is increased by 0.5 second or a total time of 9 to 10.5 seconds.

The different features of the high efficiency board save time as follows:

The omission of manual listening and ringing operations saves about 0.5 second, automatic metering for measured service also saves 0.5 second. The total direct saving in the operator's time for a regular connection on a high efficiency board is therefore only 0.5 and 1 second respectively.

The time saving features of the high efficiency boards are more apparent if we consider also the operator's time for irregularities, which consume 0.5 to 2 seconds; most of these irregularities are recalls for re-rings, which are eliminated in the high efficiency board. The additional time required for such calls on this board may be assumed, therefore, at 0.5 second, making the complete operator's time for a flat rate or measured rate connection 8 seconds, as compared with the 8.5 to 10 seconds for a flat rate call and with 9 to 10.5 seconds for a measured rate call on a standard C.B. board.

It only remains now to evaluate the call distributing feature. In the standard C.B. boards the calls appear before the operator in a very irregular way, there being only a small number of lines in a group, and the percentage of the occupied time in the busy hour therefore has to be made comparatively small (50 percent to 60 percent of the busy hour). With 8.5 seconds per call, it is theoretically 54 percent and with 10 seconds it is 64 percent.

But in a call distributing system the traffic is handled in a single large group, the peaks are lowered and operators can be loaded nearer to their physical capacity without increasing the answering time or otherwise affecting the quality of service. For European conditions 80 percent has been shown as entirely feasible and safe in actual service.

If we assume 80 percent, then the operator has 2,880 seconds available per hour for actual work; if we assume 8 seconds per call, we arrive at an average of 360 calls per hour. It should be remembered that this figure holds good for exchanges with an average of ten to fifteen operators; in smaller offices the traffic variations increase proportionally and the figure of 80 percent must be reduced to obtain the same speed of answering. For small groups of four to six operators, a load of 300 calls may be assumed. Ineffective calls (busy calls) are included. This average load of 360 busy hour calls for European high efficiency boards compares fairly well with the generally accepted busy hour load of 450 calls for semi-automatic boards in the same territories.

Let us consider, as an example, an exchange of 4,600 busy hour calls. The No. 1 C.B. board requires 20 flat rate "A" positions or 21.7 measured rate positions, but the high efficiency board handles this traffic in 12.8 positions and this secures a saving of 36 percent in flat rate and 41 percent saving in measured rate operating wages.

There remains now only the explanation of how it is possible to arrive at busy hour loads of 500 and even 600 calls obtained in actual service. A very efficient operator with the help of an intelligent class of subscribers might reduce the time per call to 6 seconds. Provided that such an operator spends 100 percent of her time on actual work (that is 3,600 seconds), she might be able to complete the above mentioned maximum of 600 connections in the busy hour. Such loads cannot, of course, be taken as a basis for any kind of comparison and should be considered as exceptional; however, they show the great flexibility of the system and its capacity for handling abnormal emergency traffic with safety over a long period.

ACTUAL INSTALLATIONS

From among the high efficiency exchanges in service, one has been selected as representative and different views from it are reproduced in Figures 6 to 11 inclusive.

3. Simple High Efficiency Boards (*C.B. Multiple Line Lamp Board*)

In the preceding pages, different features, which make possible improved service to subscribers and which at the same time facilitate the work of the operators, are outlined. Due consideration is given to the economic aspects of the problem and specimen circuits, which incorporate all the recommended features, are described.

Some telephone organizations, of course, may appreciate the advantages of increased operator's load and the shorter answering time which are possible with the multiple line lamp system, but their requirements may not be such as to justify the adoption of the other high efficiency board refinements which make the cord circuit complicated and expensive. Under such circumstances, the following features may be added to the No. 1 C.B. board:

(*a*) Multiple line lamps.
(*b*) No pilot lamps.
(*c*) Operator's bar for answering cord only.
(*d*) Alarm signal in case operator plugs in a busy line.
(*e*) Ring-back tone to calling subscriber.
(*f*) Ringing pilot signal.

From the operating standpoint, features (*a*) and (*e*) are very important. As they entail only very simple and inexpensive additional equipment, circuits fulfilling these requirements need not be much more complicated than circuits of the standard No. 1 C.B. board. In any event, the first cost of such a simple high efficiency board may be made lower than that of the standard No. 1 C.B. system.

4. No. 11 Switchboard, and Other Developments

Since the first board of the kind here described was built, other types of high efficiency C.B. boards have been developed, with partly different features and for different classes of service—notably a type now known as the "No. 11" switchboard. Further, to meet the requirements of a special field of service, an alternative type of C.B. high efficiency board, and two types of magneto multiple boards with similar features, have been developed. They will be described in subsequent articles.

A Theoretical Study of the Articulation and Intelligibility of a Telephone Circuit

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SYNOPSIS: The paper describes a theoretical study of the quantities that can be used as a measure of the transmission quality of a telephone circuit, and formulæ are developed for determining the relation between the different quantities.

The following practical applications of the theory are discussed and actual examples are given:

(1) Calculation of the relation between various quantities.

(2) Comparison of results taken with different testing techniques.

(3) Comparison of results in different languages.

(4) Determination of a suitable quantity as a criterion of transmission quality.

(5) Development of testing technique for the measurement of various quantities.

Introduction

The recent developments in international telephony have resulted in a movement towards standardisation of telephone circuits and equipment in different countries. In order to promote standardisation, it is essential, in cases where a telephone circuit passes through a number of different countries, that the results of tests and measurements carried out by the different countries on their own sections of the circuit should be capable of correlation. This is particularly so in the case of articulation and intelligibility tests since, owing to the complicated nature of these tests and the differences in testing technique that exist, the conditions existing in the tests of one country will differ from those in another. In fact, attempts to compare articulation results may often lead to errors, due to the differences of conditions existing during the tests. Apart from this, there is the further fundamental difference due to the different languages used in the various countries.

At the present time, therefore, a problem of considerable importance to the telephone engineer is that of determining how results of articulation and intelligibility tests carried out under one set of conditions can be related to tests carried out under different conditions, and how results obtained for one language can be applied to other languages. A further problem is that of deciding on a suitable unit for the criterion of the transmission quality of a telephone circuit and the development of a suitable technique for determining this quantity. The object of the work described in this paper was to obtain a solution to these problems by studying the theoretical relations between articulation and intelligibility.

General Considerations

The function of a telephone circuit is to convey ideas from one person to another and, hence, a logical measure of the efficiency of the circuit is the percentage number of ideas which are correctly transmitted over the circuit during a conversation. This value, which is known as the *Idea Intelligibility*, the *Sentence Intelligibility*, the *Sentence Articulation* or simply the *Intelligibility* of the circuit, is obtained by calling over the circuit a number of sentences so designed that each one conveys a single intelligible idea. Such a sentence, for example, would be *The man hit the big dog*. The listener records what he thinks he has heard and the percentage number of sentences correctly received is taken as the intelligibility of the circuit.

Since a large number of such sentences must be called over the circuit before a reliable average value of intelligibility is obtained, the method is laborious. To overcome this difficulty another quantity known as the *Syllable Articulation* of the circuit is often used instead of the intelligibility. To measure the syllable articulation of a circuit, a number of random syllables are called over the circuit and the articulation is defined as the percentage number of syllables correctly received. The syllables are sometimes actual words and in this case the articulation is usually called the *Word Articulation* to distinguish it from the *Syllable Articulation* which is obtained with random syllables. It is clear that the value of word articulation for a given circuit will be greater than the value of syllable articulation because, if the listener knows he is to receive actual words, he can often guess the whole word, even if he does not receive all the component sounds correctly.

There is yet a third value that can be used as a measure of the efficiency of the circuit; this quantity is known as the *Sound Articulation* or *Letter Articulation* of the circuit, and is defined as the percentage number of sounds correctly received when these are called over the circuit in the form of random syllables.

The ordinary subscriber, however, is not concerned with the percentage number of ideas, words, syllables or sounds that can be correctly transmitted over the circuit; these quantities mean nothing to him. What he is concerned with is the relative time required to convey any given piece of information over the circuit. The longer it takes him to complete his conversation, the more he has to pay for the use of the circuit and the greater the amount of his own time that is occupied in making the call.

From the subscriber's point of view, therefore, the efficiency of a telephone circuit should be judged by the relative time required to convey a given number of ideas over the circuit. For this purpose a quantity, called the *Time Efficiency* of the circuit, can be used. This quantity can be defined as the ratio of the time required to transmit a given number of ideas over an ideal circuit to the time required to transmit the same ideas over the given circuit. This quantity will thus have values ranging from zero to unity or, if expressed as a percentage, from zero to 100, the latter figure representing the ideal circuit. This quantity has also been called the *Traffic Efficiency*, but as traffic efficiency is also used to mean the percentage time during which a circuit is being usefully employed, it is suggested that time efficiency is the better expression.

In determining the overall efficiency of a telephone circuit from subscriber to subscriber, or in determining the effects of different factors and conditions on the transmission of a circuit or piece of apparatus, there are thus five quantities that can be used.

(1) *Time efficiency*, defined as the ratio of the time required to convey a given number of ideas over an ideal circuit to the time required to convey the same ideas over the given circuit.

(2) *Intelligibility*, defined as the percentage number of ideas correctly transmitted over a circuit.

(3) *Syllable articulation*, defined as the percentage number of random syllables correctly transmitted.

(4) *Word articulation*, defined in the same way as syllable articulation, except that the syllables are actual words.

(5) *Sound articulation*, defined as the percentage number of sounds correctly transmitted.

It is obvious that each of these quantities will depend on the particular technique adopted in making the tests. For instance, different values of articulation would be obtained depending on the number of sounds used to form the test syllables. Similarly, different values of intelligibility would be obtained for different languages.

Further, different results would be obtained for articulation and intelligibility by different sets of observers even when working under identical conditions and using similar testing technique.

With given observers, conditions of circuit and testing technique, a perfectly definite value can be obtained for each of the five quantities defined above. Thus a definite relation must exist between the five quantities, in spite of the fact that a certain amount of apparent guess work enters into the experimental determination of the quantities.

The object of the work described here was to establish, from fundamental principles, the theoretical relations between these various quantities. The equations that have been developed contain a number of constants, and special methods are given for evaluating these. Curves are given showing the results obtained for English, French, German and Italian and examples are given showing the close agreement between calculated and measured values.

The formulæ given here have the following uses:

(*a*) They enable the relation between time efficiency, intelligibility and the various forms of articulation to be obtained from theoretical considerations.

(*b*) They enable the results of time efficiency, intelligibility and articulation obtained by a certain testing technique to be related to the results of tests carried out under other conditions.

(*c*) They enable results obtained in one language to be related to results made in other languages.

(*d*) They enable the effect of changes in conditions and testing technique to be studied and so enable a satisfactory technique to be defined.

(*e*) They enable the various quantities to be studied from the point of view of their suitability as a criterion of transmission quality and hence allow the most suitable quantity to be chosen.

Development of Formulæ

Before giving the theoretical steps by which the formulæ are obtained, it is necessary to give a short description of the method of making articulation and intelligibility tests.

Before preparing the syllable charts for use in articulation testing in a given language, the language is analysed and a list of the most important constituent sounds is drawn up. By sound is meant a single vowel or consonant. These sounds are then formed at random into groups. These groups may be either monosyllables or multisyllables, but actually single syllables are almost always used. In the following pages the word *syllable* has been used as a general term, including monosyllables and multisyllables, which can be pronounced. In some cases the syllable lists are arranged in such a way that all sounds occur in a list with the same frequency of occurrence. In other cases the frequency of occurrence of the different sounds in the syllable lists is arranged to be the same as that of ordinary speech.

Having drawn up a list of random syllables in this way, the syllables are called over the circuit to be tested and a listener at the other end writes down what he thinks he has received. The listener's list is then compared with the called list and the percentage number of correct sounds or syllables received is determined. In order to avoid any possibility of the listener being able to guess some of the syllables, they are usually arranged so that they are not actual words. This has the disadvantage that some form of phonetic script is necessary to ensure that the syllables are correctly pronounced and recorded and this requires a special training of the operators. To overcome this trouble some tests have been made in which the syllable charts were prepared in the way already described, except that each syllable was an actual word. They therefore presented no difficulties in pronouncing or recording and special training in phonetic script was unnecessary.

As would be expected, the value of articulation obtained when using actual words is higher than the value obtained when using ordinary syllables, owing to the fact that the listener is often able to guess a word when he has not correctly received all the component sounds.

In making intelligibility tests, a number of sentences are prepared so that each sentence contains a single, intelligible idea. These sentences are then called over the circuit and the percentage number of sentences correctly received is determined. Another method is to call the sentences in the form of a question to which the listener has to reply. The caller then judges from the reply whether the listener has received the question correctly.

SOUND AND SYLLABLE ARTICULATION

Suppose that, when a series of syllables are called over a circuit, D sounds out of 100 are correctly received. Then the percentage average sound articulation is D, and the average probability that a sound will be correctly received will be $d = \frac{D}{100}$.

Hence

$$D = 100d.$$

Similarly

$$S = 100s,$$

where S is the percentage average syllable articulation and s is the average probability of receiving a syllable correctly. It should be noted that in this paper the discussion deals only with average quantities, so that where, in the following pages, the words, articulation, intelligibility, time efficiency and probability occur, they refer to the average values.

If a syllable consists of one sound only, then clearly the probability of receiving the syllable correctly is the same as the probability of receiving the sound correctly. Hence

$$s = d.$$

If the syllable contains two sounds, then the probability of receiving the syllable correctly is the probability of receiving both the component sounds correctly. Hence

$$s = d^2.$$

In general, if the syllable contains n sounds, we have

$$s = d^n$$

or

$$S = 100\left(\frac{D}{100}\right)^n.$$

Suppose that the lists used for articulation contain a percent of syllables with one sound, b percent with two sounds and c percent with three sounds, then the average probability of receiving a syllable correctly will be

$$s = \frac{1}{100}(ad + bd^2 + cd^3)$$

and, therefore, the syllable articulation will be given in terms of the sound articulation by the expression

$$S = a\left(\frac{D}{100}\right) + b\left(\frac{D}{100}\right)^2 + c\left(\frac{D}{100}\right)^3.$$

For other arrangements of sounds and syllables a similar formula can be obtained.

Syllable and Word Articulation

When a syllable is called over a circuit, each of the component sounds can be mistaken for a certain number of other sounds, and, since each of the alternatives of a given sound in the syllable can occur with each of the alternatives of all the other sounds in the syllable, there are a large number of syllables for which the correct one can be mistaken.

In general, if the syllable can be mistaken for $N - 1$ other syllables, i.e., there are N possible syllables, any one of which may be received when the correct one is called, then the probability of receiving the syllable correctly is $1/N$.

We can, therefore, consider the listener as mentally setting out these N alternatives and choosing one of them.

When the listener knows he is to receive a syllable which is an actual word, then, obviously, he is able mentally to reject some of the alternative syllables because they are not actual words. He has only a limited number of alternatives, therefore, from which to choose, and the word articulation is consequently higher than the corresponding value of syllable articulation.

Let M be the number of alternatives that can be received when the listener knows he is to receive an actual word. Then there are $M - 1$ wrong words for which the correct one can be mistaken. In this case we can consider that the listener sets out the N possible alternatives, one of which is correct, and then crosses out all the alternatives that are not actual words, being left with M possible alternatives of which one is correct.

Now the number of incorrect words $M - 1$ for which the correct one can be mistaken is a certain fraction of the number of incorrect syllables $N - 1$ for which the correct one can be mistaken.

We can, therefore, put

$$M - 1 = k(N - 1).$$

The value of k being less than unity and being the proportion of syllables, of any given number of sounds, which are actual words in the language under consideration.

Since

$$k = \frac{M-1}{N-1}$$

we have

$$M = 1 + k(N - 1).$$

If w is the probability of receiving the word correctly and W is the percentage word articulation, we have

$$W = 100\,w = \frac{100}{M} = \frac{100}{1 + k(N-1)}.$$

But

$$\frac{1}{N} = s = \frac{S}{100}.$$

Hence

$$W = \frac{100}{1 + k\left(\frac{100}{S} - 1\right)}.$$

This expression thus enables the relation between the word articulation and syllable articulation to be determined if the value of k is known.

Articulation and Intelligibility

In making intelligibility tests, sentences, each conveying a single intelligible idea, are called over the circuit. Now it is clear that some words in a sentence play a greater part in conveying the idea than the others. Consider the sentence *The man hit the big dog.* Here, practically the whole idea is carried by the words *man, hit, big* and *dog,* so that, even if only these words were received correctly, the correct idea would be received. These words may therefore be considered as the key words of the sentence since they convey practically the whole of the idea. In general, therefore, in determining the relation between intelligibility and articulation, it is only necessary to consider the effect of the key words of a sentence.

Assume that, on the average, a sentence will require m key words in order to convey an intelligible idea, and let the average articulation of these key words be V. Then, when a word is called there will be, on the average, $100/V$ alternatives. Now each of the m key words will have $100/V$ alternatives, so that the total number of possible arrangements of m key words that may be received when the given sentence is called will be $(100/V)^m$.

Suppose that the listener was receiving merely arrangements of m key words, i.e., the words did not necessarily convey an intelligible idea. Then he would have to select mentally one of the $(100/V)^m$ possible arrangements. He could thus mistake the correct arrangement for $(100/V)^m-1$ wrong arrangements.

Now, suppose that the listener knows that the arrangement of key words that he is to receive will convey an intelligible idea. Then he will be able mentally to reject a large number of the $(100/V)^m - 1$ arrangements because they do not convey intelligible ideas.

He will, therefore, be left with a certain number of arrangements $h\{(100/V)^m - 1\}$ for which he can mistake the correct one.

The probability of his receiving the sentence correctly is, therefore,

$$\frac{1}{1 + h\left\{\left(\frac{100}{V}\right)^m - 1\right\}}.$$

Hence the percentage intelligibility I will be given by the expression

$$I = \frac{100}{1 + h\left\{\left(\frac{100}{V}\right)^m - 1\right\}}.$$

This gives the intelligibility in terms of the average key word articulation V.

In the previous paragraph, under *Syllable and Word Articulation,* it was shown that the relation between word and syllable articulation was given by the expression

$$W = \frac{100}{1 + k\left(\frac{100}{S} - 1\right)}$$

and under *Sound and Syllable Articulation* it was shown that the relation between sound and syllable articulation was

$$S = 100\left\{\frac{D}{100}\right\}^n.$$

Combining these two expressions we have for the general case of words with n sounds

$$W_n = \frac{100}{1 + k_n\left\{\left(\frac{100}{D}\right)^n - 1\right\}},$$

where D is the ideal sound articulation.

The average key word articulation is then given in terms of the word articulation by the expression

$$V = \frac{1}{100}\Sigma p_n W_n,$$

where p_n is the percentage frequency of occurrence of words containing n sounds in ordinary speech.

The intelligibility is therefore given in terms of the ideal sound articulation by the expressions

$$I = \frac{100}{I + h\left\{\left(\frac{100}{V}\right)^m - 1\right\}}$$

$$V = \frac{1}{100}\Sigma p_n W_n$$

$$W_n = \frac{100}{I + k_n\left\{\left(\frac{100}{D}\right)^n - 1\right\}}.$$

The value of sound articulation D, on which these formulæ are based, is the ideal value, i.e., the value that would be obtained on the assumption of ideal pronunciation by the caller. The corresponding value of intelligibility is, therefore, called the ideal value. In the case of actual speech the value of sound articulation obtained falls short of the ideal value. If, therefore, we denote the actual sound articulation for syllables of *n* sounds by D_n, the actual value of intelligibility will be given in terms of the actual sound articulation by the expressions

$$I = \frac{100}{1 + h\left\{\left(\frac{100}{V}\right)^m - 1\right\}}.$$

$$V = \frac{1}{100}\Sigma p_n W_n.$$

$$W_n = \frac{100}{1 + k_n\left\{\left(\frac{100}{D_n}\right)^n - 1\right\}}.$$

This question of ideal and actual sound articulation is discussed more fully later under *Average Sound Articulation.*

INTELLIGIBILITY AND TIME EFFICIENCY

The time efficiency was defined as the time required to call a given number of ideas over an ideal circuit to the time required to call the same ideas over the given circuit.

Assume that a time of *t* seconds is required to call an idea. Then, if *A* ideas are called over a circuit which gives an intelligibility of $I\%$, only $AI/100$ of these ideas will be correctly received and the remaining $A\{1 - I/100\}$ ideas will have to be called again. After calling these again there will still be $A\{1 - I/100\}^2$ ideas which are not correctly received and must therefore be called a third time. If this is continued, then the total time required to call the *A* ideas will be given by the expression:

$$t' = At\left\{1 + \left(1 - \frac{I}{100}\right) + \left(1 - \frac{I}{100}\right)^2 + \cdots\right\} = \frac{100\,At}{I}.$$

Now if I' is the value of intelligibility obtained by the caller and listener over the ideal circuit and I is the value obtained over the given circuit, the time efficiency for this caller and listener will be

$$T = \frac{\frac{100\,At}{I'}}{\frac{100\,At}{I}} = \frac{I}{I'}.$$

Hence the time efficiency is numerically equal to the ratio of the intelligibility of the given circuit to the intelligibility of an ideal circuit. The intelligibility obtained by given observers over an ideal circuit is not 100%, of course, because, as pointed out under the heading *Average Sound Articulation* the average sound articulation may be less than 100% for an ordinary speaker. The intelligibility obtained over the ideal circuit will, however, be very nearly 100%, so that the time efficiency for a given circuit has very nearly the same value as the intelligibility for that circuit.

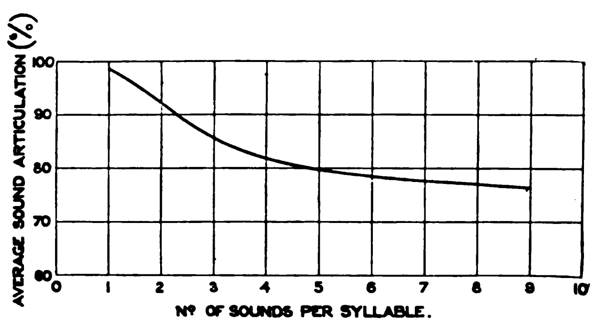

Figure 1.

If perfect observers are assumed so that their value of intelligibility over the ideal circuit is actually 100%, their value of time efficiency for any given circuit will be exactly equal to the intelligibility. In other words, what may be called the *Ideal Time Efficiency* of a circuit is equal to its *Ideal Intelligibility.*

AVERAGE SOUND ARTICULATION

The intelligibility was given above in terms of D_n, the average sound articulation for syllables of *n* sounds. This quantity D_n requires some explanation. If a number of syllable lists are prepared, one list being composed entirely of syllables having two sounds, another being composed entirely of syllables having three sounds and so on, and these are called over an ideal circuit in the same way as the words in ordinary speech, then it will be found that the average sound articulation for a list depends on the number of sounds in the syllables of the list. A curve illustrating the results obtained in this way is shown in Fig. 1. This curve shows that the greater the number of sounds in the syllable, the smaller the value of average sound articulation obtained. This is due partly to the fact that the caller tends to slur over some of the sounds when the syllable contains a large number of sounds, and partly to the fact that the listener tends to become confused when he receives syllables containing a large number of sounds. This fact only occurs, of course, when the caller is pronouncing the syllables at natural speed and with a natural intonation as used in speech; it would naturally be possible to obtain as good a value of articulation for the long syllables as for the short ones if the caller were to speak very slowly and were to pronounce the sounds with unusual care.

This effect has been taken into account in calculating the intelligibility curve given in Fig. 4.

The value of average sound articulation for any given syllable list will also depend on the proportion of the different sounds in the list. If the different sounds all have the same frequency of occurrence, one value of average sound articulation will be obtained while, if the sounds occur in the list with the same frequency as in speech, a different value of average sound articulation will be obtained. For this reason it is always desirable to state, when quoting a value of sound articulation, how the various sounds were weighted in the test lists.

In this connection it is of interest to study the following figures which give the estimated values of sound articulation for English, French, German and Italian, both for equal weighting and speech weighting, for two particular sets of circuit conditions

Language	Average Sound Articulation			
	Circuit A		Circuit B	
	Weighting		Weighting	
	Equal	Speech	Equal	Speech
English........	72.3	75.3	54.0	56.9
French.........	71.6	72.4	54.2	58.1
German........	71.2	74.2	55.5	56.4
Italian.........	72.9	73.4	57.6	59.1
Mean..........	72.0	73.8	55.3	57.6

These figures show that the corresponding values of sound articulation for the different languages are approximately the same, both for the equal weighting and for the speech weighting. Results of sound articulation in different languages can therefore be compared directly with small error.

Since different callers vary in their pronunciation and different listeners vary in their ability to interpret correctly the sounds they receive, the value of average sound articulation obtained for a given circuit will be different for different testers.

In order to take this effect into account, we can consider the sound articulation D obtained over any given circuit as being the product of two factors, i.e.

$$D = D_e \times D_i.$$

Here D_e is the factor just discussed which is independent of the properties of the circuit and which is a measure of the average enunciation of a speaker. It is the sound articulation that would be obtained over an ideal circuit and may be termed the *Average Sound Enunciation.*

The factor D_i depends entirely on the properties of the circuit, and is the sound articulation that would be obtained over the circuit on the assumption of ideal enunciation. It may, therefore, be called the *Ideal Sound Articulation* of the circuit.

Determination of Constants

The establishment of these formulæ has necessitated the introduction of a number of somewhat unusual constants and special methods have had to be developed for evaluating these constants. A description of these methods is given below.

SOUND AND SYLLABLE ARTICULATION

The formula given above for the relation between the sound and syllable articulation is of the form

$$S = \Sigma a_n \left(\frac{D}{100}\right)^n,$$

where a_n is a constant which expresses the percentage number of syllables that have n sounds.

The value of a_n has therefore to be determined for all values of n occurring in the syllables used for the articulation tests. This can easily be done for any given set of tests by analysing the syllables that are used and determining what percentage of them contain one sound, two sounds and so on up to the maximum value of n used in the tests.

SYLLABLE AND WORD ARTICULATION

The expression giving the relation between word and syllable articulation is

$$W = \frac{100}{1 + k\left(\frac{100}{S} - 1\right)},$$

where k is a constant whose value is the ratio of the number of syllable arrangements that are actual words to the total possible number of such arrangements.

The value of k will depend, of course, on the nature of the syllable arrangements under consideration; the value for two syllable arrangements, for instance, will be different from that for single syllable arrangements. The method developed for determining this constant was to write on a series of cards the different sounds occurring in the language under consideration. Each card had one sound on it but several cards carried the same sound, the number of cards bearing a given sound being proportional to the frequency of occurrence of that sound in the language.

The cards bearing consonants were then all mixed up together and placed in a box, while the vowels were also mixed up together and placed in another box. Now suppose that single syllables are being dealt with; these can be of various forms, for instance, consonant-vowel-consonant or vowel-consonant-consonant. The different forms that can occur and their frequency of occurrence are found from an examination of the language. Suppose that single syllables of the form consonant-vowel-consonant are being considered. A card was drawn from the consonant box, then one from the vowel box and finally one from the consonant box again. These three cards were placed side by side on the table in the order in which they were drawn and the sounds on them therefore formed a syllable of the desired form. This was examined and a note was made as to whether it was an actual word or not. The three cards were then put on one side and the procedure was repeated with other cards from the boxes.

After this has been done a large number of times, it will be found that a certain percentage of the syllables formed are actual words. This percentage is the value of k for the particular type of syllable investigated. In order to obtain an average value of all forms of, say, single syllables it is necessary to determine k for the different arrangements of consonants and vowels and then multiply each value of k by the frequency of occurrence of the corresponding arrangement in the language.

ARTICULATION AND INTELLIGIBILITY

The relation between the average sound articulation and intelligibility involves the following constants, m, h, p_n and k_n.

The constant m is the average number of key words required to convey a single intelligible idea. The value of m can be obtained by analysing sentences which can be considered to convey an intelligible idea and determining how many key words each contains. If special test sentences are used in measuring the value of intelligibility, then m should, of course, be obtained by analysis of these test sentences.

Having found a value for m, the value of h can be determined. The constant h is the ratio of the number of arrangements of m key words which can be said to convey an intelligible idea to the total possible number of such arrangements. The method used to determine the value of h was to choose m key words at random and arrange them in random order. These were then inspected to determine whether they could be said to convey an intelligible idea and the number of arrangements satisfying this condition, expressed as a percentage of the total number of arrangements tried, was taken as the value of h.

The value of the constant k_n has next to be determined for different values of n. The procedure to be adopted varies somewhat according to the language to be investigated, and it is not possible in a short paper of this nature to give in full the procedure for all possible cases. Sufficient information, however, is given here to indicate the lines along which the determination is carried out.

Since k_n is the ratio of the number of words of n sounds, B_n, to the number of possible arrangements of n sounds, A_n, it is evaluated by determining the values of A_n and B_n separately.

The value of B_n, the number of possible words of n sounds in the language, or the number known by the average subscriber, is determined by analysing a suitable dictionary and is a straightforward, though rather laborious, task.

The determination of A_n, the number of possible arrangements, is much more complicated and it is here that the chief difficulty occurs.

Consider, first, the case of a language consisting of words which are formed entirely at random so that there are no prefixes or suffixes common to a number of words. In this case the determination of B_n would be comparatively simple. Take the case of words having five sounds. Then, if a consonant is denoted by C and a vowel by V, the following arrangements of five sounds could be obtained:

VVVVV
VVVVC
VVVCV
VVCVV
VCVVV
CVVVV
VVVCC
VVCVC
VCVVC
CVVVC
VVCCV
VCVCV
CVVCV
VCCVV
CVCVV
CCVVV
VVCCC
VCVCC
CVVCC
VCCVC
CVCVC
CCVVC
VCCCV
CVCCV
CCVCV
CCCVV
VCCCC
CVCCC
CCVCC
CCCVC
CCCCV
CCCCC

Now, suppose, for example, that in the language under investigation two or more vowels are never adjacent in a word and that more than two consonants are never adjacent. The following arrangements are thus the only ones that need be considered:

CCVCC
CCVCV
CVCCV
VCCVC
CVCVC
VCVCV
VCVCC

From an analysis of the language under investigation it is possible to determine how many different consonants and vowels can occur in the different positions. Take the arrangement *CCVCV*, for example, and assume that it is found that when two consonants occur together there are, on the average, only 24 different arrangements that are likely to occur. In the same way, assume that it is found when a single vowel occurs in the body of the word it may be any one of 15 possible vowels. Similarly, assume that 22 consonants can occur alone in the body of the word and that 9 vowels can end a word. Then the total number of possible arrangements that could occur of the form *CCVCV* will be $24 \times 15 \times 22 \times 9$. In a similar way the total possible number of other arrangements of five sounds can be obtained and, hence, the total number of all the possible arrangements of five sounds. This value divided into the total number of possible words of five sounds then gives the value of k_5 for the language in question.

In a similar way the value of k_n for other values of n can be obtained.

In the previous discussion it was assumed that no common prefixes or suffixes occurred. When these do occur in a language they require a modification of the procedure to be followed in determining the word articulation. There are two types of terminations and prefixes that occur in practice and, since the effect on the articulation is different, they must be considered separately. The termination of the first type is that which is added to adjectives in certain languages in order to make the adjective agree with the gender of the noun to which it belongs. Another termination of this type is the termination added to verbs to show person and number, or to nouns and adjectives to show case.

The sounds constituting this type of ending can be said to carry little or none of the meaning of the word and, in fact, in a language like English they are almost completely absent.

From the point of view of articulation, therefore, words of this type can be considered as consisting of a root which carries practically the whole of the meaning of the word and an ending which can be neglected.

The word articulation for a word of this type, consisting of n sounds and having a termination of r sounds, would be

$$W_n = \frac{100}{1 + k_n\left\{\left(\frac{100}{D_n}\right)^{n-r} - 1\right\}}.$$

The number of possible arrangements A_n which forms the denominator of k_n, would, in this case, be the number of possible arrangements of $n - r$ sounds.

The second type of termination or prefix is that which, added to the root of the word, modifies its meaning in some way. Examples of this type of ending in English are *able* and *tion* and examples of prefixes in English are *anti* and *un*.

Since prefixes or suffixes of this type do add definitely to the meaning of the root they cannot be neglected as in the case of the first type. It is not permissible, however, to treat the sounds forming these prefixes and suffixes in the same way as the other sounds in the word for the following reasons. When a common suffix or prefix such, for example, as *anti* occurs in a word, the probability that this group of sounds will be correctly received is very much greater than would be determined by considering it as four separate sounds. In fact, on the average, the termination or prefix appears to be received more as though it were a single sound than as if it were a collection of sounds. A close approximation to the actual measured articulation is therefore obtained by considering a word of n sounds with a termination of r sounds as though it consisted of $n - r + 1$ sounds. The expression for word articulation thus becomes:

$$W_n = \frac{100}{1 + k_n\left\{\left(\frac{100}{D_n}\right)^{n-r+1} - 1\right\}}.$$

The value of A_n used to determine k_n is, in this case, the number of possible arrangements of $n - r$ sounds.

In any language, words of all these types usually occur. The average value of W_n is therefore obtained by calculating W_n for the different types of words, weighting each value by the percentage frequency of occurrence of the corresponding type of word, and taking the mean of these weighted values.

Comparison of Calculated Results with Measured Results

A number of examples, in which the values of articulation and intelligibility calculated from the formulæ given here have been compared with the corresponding values obtained by actual measurements, are given below in order to show that good agreement is obtained between measured and calculated values.

Sound and Syllable Articulation

An experimental curve is given in Fig. 2 showing the relation between sound articulation and syllable articulation for the case in which lists of single syllables were used having half the syllables composed of a vowel and a consonant and the other half composed of a vowel and two consonants. In this case the formula giving the syllable articulation in terms of the sound articulation is

$$S = 50\left\{\left(\frac{D}{100}\right)^2 + \left(\frac{D}{100}\right)^3\right\}.$$

In Fig. 2 the dotted curve was plotted from the above expression and the full line curve from the measured results.

It will be seen that the agreement between the two is good, the maximum difference being only a few percent. This small difference is probably due to the fact that when a listener receives a syllable of the form vowel plus consonant he tends to add an additional consonant before the vowel. In the same way for a syllable of the form consonant plus vowel there is a tendency to add a final consonant. These added consonants were counted as errors when estimating the articulation from the test results and would tend therefore to give a lower value of sound articulation than the corresponding calculated value.

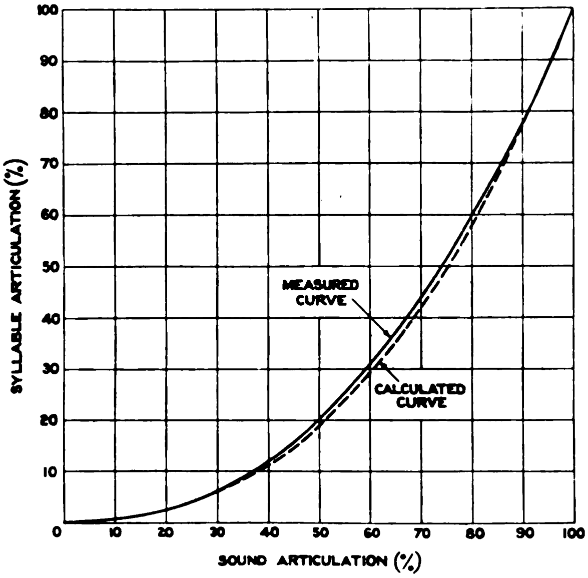

Figure 2.

Syllable and Word Articulation

In Fig. 3 is given a curve obtained from measured results showing the relation between word articulation and syllable articulation.

The formula for this case is

$$W = \frac{100}{1 + k\left(\frac{100}{S} - 1\right)}.$$

The value of k was determined for syllables formed of one vowel plus one consonant and for syllables formed of one vowel plus two consonants, and was found to be 0.48 and 0.39, respectively. Since the syllables and words used in this set of tests consisted half of the form vowel plus consonant and half of the form two consonants plus vowel, the value k was taken as

$$\frac{0.48 + 0.39}{2} = 0.435.$$

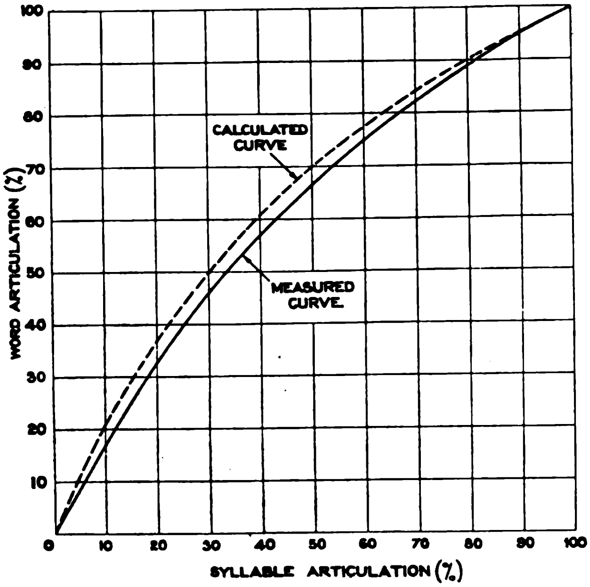

Figure 3.

The curve plotted from this expression is shown by a dotted line in Fig. 3 and the experimental curve is shown by the full line.

The two curves are in good agreement and do not differ by more than a few percent.

Articulation and Intelligibility

In Fig. 4 two curves are shown, giving the relation between intelligibility and ideal sound articulation. One of these curves was calculated from the formulæ given in this paper and the other was obtained by actual measurement of intelligibility and sound articulation.

These two curves are in good agreement, showing that the theory gives results which approximate closely to the actual measured values.

As an additional check on the theory, some intelligibility tests were made in English and German under the same conditions.

The ratio of the German intelligibility to the English intelligibility was found to be 1.9, while the corresponding calculated value was 1.7.

These various results show that there are only small differences between the calculated and measured results. The differences that do exist are only such as would be expected, owing to the difficulty of making accurate intelligibility tests.

Practical Application of Theory

This theory was developed primarily to enable results of different articulation and intelligibility tests to be compared, and this is one of its most useful applications. There are, however, a number of other applications which are of sufficient interest to be mentioned here.

Since the theory shows on what factors the articulation or intelligibility of a circuit depends, it enables a suitable testing technique to be developed so that reliable and consistent results can be obtained with the least amount of work.

The theory also enables a study to be made of the different quantities that have been used to measure the transmission quality of a telephone circuit, and so makes it possible to select the most suitable quantity as a criterion.

In addition, it is interesting to make use of the theory to study the relative advantages of different languages from the telephone user's point of view.

These various applications are dealt with in the following paragraphs.

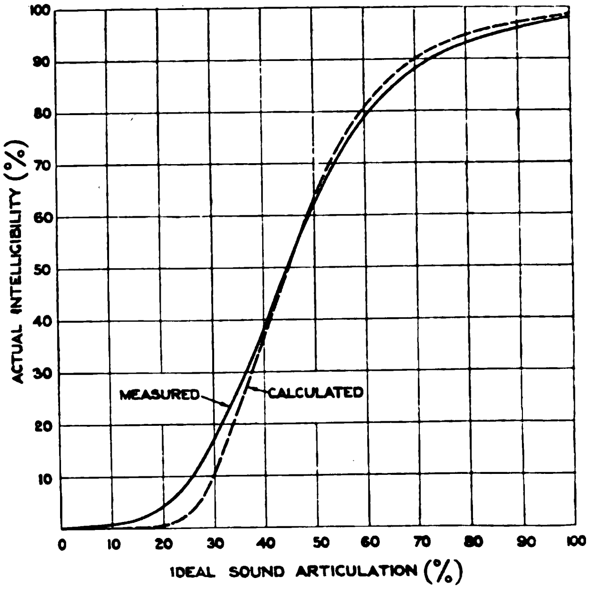

Figure 4.

Correlation of Results

During the last few years, several methods of making articulation tests have been published and, as these all differ in certain particulars, the results cannot be compared directly. As an example of the way in which it is possible to make a correct comparison by means of the theory given here, consider the two following testing techniques.

Technique A is that described by H. Fletcher in the *Journal of the Franklin Institute*, Vol. 193, No. 6, June, 1922.

Technique B is that described by K. Küpfmüller in *Europäischer Fernsprechdienst*, No. 5, July, 1927.

Assume that a value of syllable articulation of 60% is obtained for a given circuit by means of testing technique A which was based on the English language.

In this technique 20% of the test syllables consisted of two sounds and 80% of three sounds. Hence the syllable and sound articulation are related by the expression

$$S = 20\left(\frac{D}{100}\right)^2 + 80\left(\frac{D}{100}\right)^3.$$

From this the value of sound articulation corresponding to the syllable articulation of 60% is found to be 83.2%.

In these tests the various sounds had all approximately the same weighting, so that the value of 83.2% is for equally weighted sounds. Now the ratio between sound articulation for equally weighted sounds to the sound articulation for sounds weighted as in speech is approximately constant for all languages and is 0.96. Further, the average sound articulation obtained over a given circuit for sounds weighted as in speech is practically the same whatever language is used. Hence the value of sound articulation for sounds weighted as in German speech may be taken as

$$\frac{83.2}{0.96} = 86.8\%.$$

In the testing technique B, which was based on the German language, 25% of the syllables had two sounds, 51% had three sounds, 21% had four sounds and 3% had five sounds.

Hence the syllable articulation is given in terms of the sound articulation by the expression

$$S = 25\left(\frac{D}{100}\right)^2 + 51\left(\frac{D}{100}\right)^3 + 21\left(\frac{D}{100}\right)^4 + 3\left(\frac{D}{100}\right)^5$$

and the value of syllable articulation corresponding to the sound articulation of 86.8% is therefore 64.5%.

This shows that a circuit which would give a value of syllable articulation of 60% according to technique A would give a value of 64.5% according to technique B. There is thus a difference between the results given by the two techniques and this example serves to emphasize the need for a standardisation of testing technique. This question is discussed further under the heading *Testing Technique.*

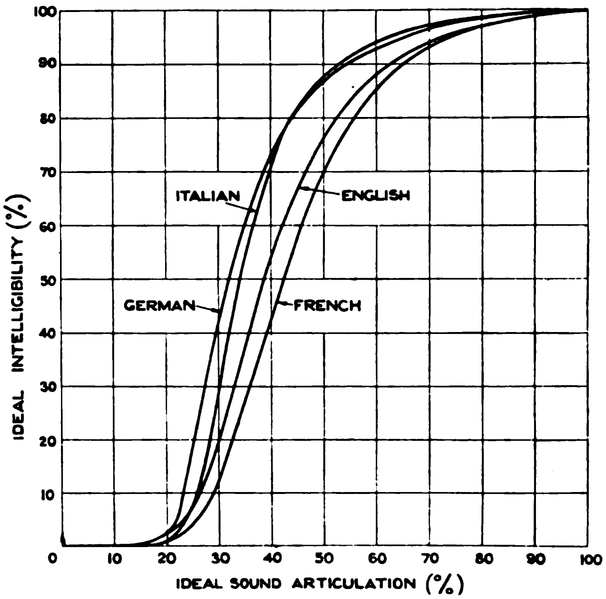

Figure 5.

As a second example of the comparison of results taken under different conditions, assume that a value of ideal intelligibility for French of 80% has been obtained and it is required to determine what the corresponding value would be for Italian. This case is solved directly by means of the curves given in Fig. 5. From these curves it will be seen that the value of 80% for French corresponds to a value of 92.0% for Italian.

As a third example suppose that it is required to find what value of intelligibility in English would be obtained over a circuit giving an ideal sound articulation of 50%. From Fig. 5 it will be seen that the ideal intelligibility for English corresponding to the ideal sound articulation of 50% is 76%, while the actual value of intelligibility calculated for a certain testing crew is obtained from Fig. 4 and is 63%.

TESTING TECHNIQUE

It is not proposed to go into the question of testing technique in any great detail, since various publications by different authors have already dealt with this question. There are, however, certain points which the theory shows to be of importance and, since these points do not appear to have received consideration up to the present, they are discussed below.

Since the syllable articulation for a syllable of n sounds is given in terms of the sound articulation by the expression

$$S = 100\left(\frac{D}{100}\right)^n$$

it follows that, for a given value of sound articulation, the value of syllable articulation will depend on the number of sounds used in the test syllables.

Hence it is of importance to standardise the number of sounds per syllable that are to be used for forming syllable lists for articulation testing. As an example of the difference that would result in the use of a different number of sounds per syllable, take the case of three observers using, respectively, 2-sound syllables, 3-sound syllables and 4-sound syllables. The values of syllable articulation that these three observers would obtain over a circuit giving a sound articulation of, say, 80% would be, 64%, 51.2% and 41% respectively.

Even if it were decided to use, say, only two- and three-sound syllables it would be necessary to specify the exact percentage of each type of syllable to be used in the lists, since a change in these percentages would alter the value of syllable articulation obtained.

A further effect which should receive attention is that mentioned on page 173 under *Average Sound Articulation* and illustrated in Fig. 1. It was pointed out there that the actual sound articulation obtained depended on the number of sounds in the words or syllables. This effect is most marked, of course, in speech where the pronunciation tends to be less clear than in articulation tests. Experiments have shown, however, that this effect is present even in ordinary articulation tests where the speaker is articulating carefully, and even with as low a number as two or three sounds per syllable. This is an additional argument for standardising the number of sounds per syllable, and is also an argument for calibrating the operators in terms of some standard reference circuit as suggested in the next section.

Some observers have used syllable lists in which the sounds all had equal weighting, while others have used lists in which the sounds had the same weighting as in speech. The figures given under *Average Sound Articulation* show that there is not much difference between the two values of sound articulation and since, in any case, the ratio between the two values is practically constant, there appears to be little reason for using one value rather than the other.

In the case of intelligibility tests, owing to the much more complicated factors involved, it is even more necessary to standardise the testing technique if consistent results are to be obtained.

The expressions given under the heading *Articulation and Intelligibility* for calculating the intelligibility involve the following factors, D_n, k_n, p_n, h and m, and these depend in turn on the following conditions:

(i) All conditions already discussed for sound articulation.
(ii) Number of words of different numbers of sounds known by the tester.
(iii) The number of key words used per sentence.

Since the factors which depend on the knowledge of the testers are so difficult to control, it is doubtful whether any really reliable results would be obtained by making intelligibility tests. It is suggested, therefore, that only values of sound articulation should be measured and that suitable average values of the above constants should be decided upon from a study of the different languages. When a value of intelligibility is required it should be obtained by calculation from a measured value of sound articulation, using the average values of the constants. The value of intelligibility so obtained would then be the average for the given language. This question is dealt with in greater detail in the next section.

CHOICE OF A QUANTITY FOR THE MEASURE OF TRANSMISSION QUALITY

Five quantities have been defined above, each of which can be used as a measure of the efficiency of a telephone circuit.

These five quantities are:

(1) Time Efficiency.
(2) Intelligibility.
(3) Word Articulation.
(4) Syllable Articulation.
(5) Sound Articulation.

It has already been shown that there is a perfectly definite relation between each of these five quantities so that, theoretically, there is no reason why any one of these quantities should be chosen as a measure of circuit efficiency rather than another. From a practical point of view, however, it is desirable to choose the quantity so that, when some change in a given telephone circuit is made, the change in the quantity is directly proportional to the effective change in the transmission quality of the circuit.

As an example of this, take the case of some change in the constants of a telephone circuit which brings about an improvement in the average sound articulation from 75% to 85%. Tests have shown that this change of 10% in average sound articulation corresponds to a change in syllable articulation of 17%, to a change in word articulation of 14%, to a change in intelligibility of 4% and to a change in time efficiency of just under 4%.

The question now is, is the improvement in the circuit, as judged by practical standards, equal to 10%, 17%, 14% or 4%?

The answer to this question is that, since the subscriber naturally judges the circuit on a time or cost basis, the time efficiency gives the true criterion of the improvement in the circuit.

So far it has been tacitly assumed that the subscribers using the circuit are speaking their own language and are fully acquainted with it. In many cases, especially for international circuits, the subscribers are speaking a foreign language with which they are not entirely familiar.

In this case the values of intelligibility and articulation that would be obtained by people speaking a foreign language would obviously be less than those obtained by natives speaking the language. The question arises, therefore, as to whether the improvement in the circuit from the point of view of a subscriber speaking a foreign language is truly measured by the improvement in the intelligibility of the circuit, assuming this to be measured by natives who are completely familiar with the language.

For this reason it is of considerable interest to consider what modifications in the expressions for the intelligibility of a circuit should be introduced to enable them to be applied to the case of someone speaking a foreign language with which he is not entirely familiar.

The average sound articulation obtained by foreigners for a given circuit will obviously be less than the value obtained by natives, because, in addition to errors due to imperfections of the telephone circuit, there will be errors due to a faulty pronunciation and to the inability of the listener to distinguish clearly between similar sounds.

A further modification is introduced by the fact that the foreigner has only a limited vocabulary.

Consider a listener receiving over a telephone circuit a number of random words of a foreign language. If a given word is one that he knows, then we can consider him as setting out all the possible alternatives to the called word, eliminating those which he thinks are not words and then selecting from what are left the word he thinks is the correct one. Owing to his limited vocabulary, he will reject certain arrangements which are actual words because he does not happen to know them. The results will be that the foreigner is left with fewer words from which to choose than the total possible number from which the native would have to choose. The probability, therefore, of the foreigner getting the word correct, when it is one that he knows, is greater than that of the native. This effect is, of course, modified by the fact that only a limited number of the called words will be known to the foreigner.

The word articulation W'_n for the foreigner will thus be given by the expression

$$W'_n = \frac{100\, q'}{1 + qk_n \left\{ \left(\frac{100}{vD} \right)^n - 1 \right\}},$$

where q is a factor expressing the fraction of the total possible words that the foreigner knows, q' is the fraction of the words he knows in ordinary speech and v is the ratio of the average sound articulation of the foreigner to that of the native.

As before we shall have the average key word articulation V' given by the expression

$$V' = \frac{1}{100} \Sigma p_n W'_n.$$

Also the intelligibility will be given in terms of the average key word articulation by the expression

$$I' = \frac{100}{1 + h\left\{\left(\frac{100}{V'}\right)^m - 1\right\}}.$$

It is true that, to be strictly accurate, the expression for the intelligibility should involve factors similar to q and q', used in the expression for the word articulation, since it is conceivable that the foreigner might receive a group of key words which conveyed no intelligible idea to him, although it would to a native. Since, however, cases of this kind would be extremely rare if the foreigner knows enough of the language to attempt to speak it over the telephone at all, the necessary factors would be very nearly unity and can therefore be neglected.

We therefore have the expressions

$$W'_n = \frac{100\,q'}{1 + qk_n\left\{\left(\frac{100}{vD}\right)^n - 1\right\}},$$

$$V' = \frac{1}{100} \Sigma p_n W'_n,$$

$$I' = \frac{100}{1 + h\left\{\left(\frac{100}{V'}\right)^m - 1\right\}}.$$

Suitable values have been chosen for q, q' and v for the case of someone whose knowledge of a foreign language is very limited but who just knows enough to speak it on the telephone. This, of course, is the limiting case, and the results have been plotted in Fig. 6, together with the corresponding curve for the native. From these it will be seen that, taking the previous case of an increase in sound articulation from 75% to 85%, an increase of 4% in intelligibility is obtained for the case of the native and an increase of 6.5% in the case of the foreigner. These values of 4% and 6.5% can be considered as the limiting values so that, for most cases of international circuits, a value in between 6.5 and 4 would be obtained.

The value of intelligibility that the foreigner would obtain over an ideal circuit is seen from the curve to be about 91.5%, since this is the maximum value to which the foreigner's curve tends.

The foreigner's time efficiency can be determined by dividing any given value of intelligibility by the value 91.5.

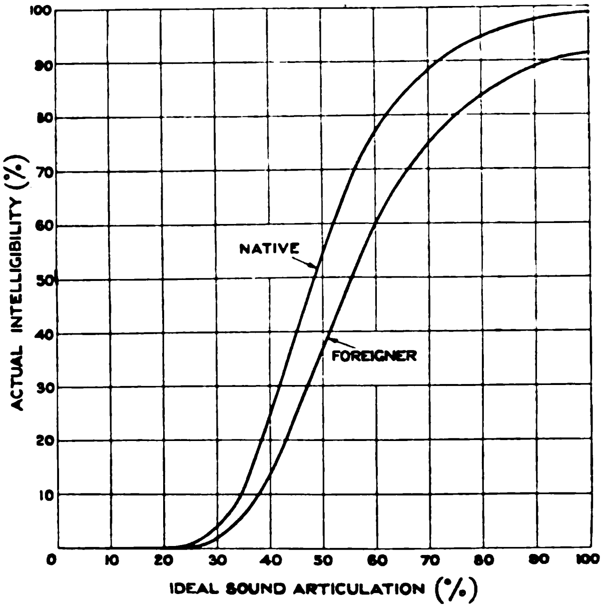

Figure 6.

In this way the increase in the foreigner's time efficiency corresponding to the increase in intelligibility of 6.5 is found to be about 7.1%. This value of 7.1% increase in the foreigner's time efficiency for the circuit corresponds to the native's increase of 4% in time efficiency.

This demonstrates that the improvement of the circuit from the foreigner's point of view is greater than it is from the native's point of view. Hence the time efficiency as obtained for a native is not a true criterion of the circuit from the foreigner's point of view. Since international circuits are often used by subscribers who are not talking their own native language, it is important to consider the effect of changes in circuit and apparatus from the foreigner's point of view as well as the native's point of view.

For this purpose, no one value either of time efficiency, intelligibility or articulation can be considered as satisfactory. But there is no doubt that the time efficiency, or, what is practically the same, the intelligibility, as obtained for a native, does give a better general idea of the circuit efficiency than the corresponding values of articulation.

As a general criterion of circuit performance, therefore, it is suggested that the time efficiency, as obtained for a native, should be used.

There is, however, another aspect of this question, concerning the choice of a suitable measure of circuit efficiency, which leads to rather different results, and that is from the point of view of drawing up specifications, giving guarantees and correlating test results.

For this purpose some quantity which is fundamental, is easily defined, is easily measured, and is independent of testing technique, is essential. Now, as pointed out in the previous section, the intelligibility, and therefore the time efficiency, depend on so many factors which are extremely difficult to control, since they depend on the personal characteristics of the testers. Time efficiency cannot, therefore, be considered as satisfactory from the point of view of guarantees and specifications.

It is therefore suggested that what has been defined in this paper as the *Ideal Sound Articulation* of a circuit should be used. This quantity is defined as the sound articulation that would be obtained over a given circuit on the assumption of ideal testers, both at the calling and listening ends of the circuit. As already shown, this quantity is practically the same for any language, so that results obtained in one country could be directly compared with results of other countries. It is the most fundamental quantity of all since syllable articulation, word articulation, intelligibility and time efficiency are all based on it and calculated from it. Further, the ideal sound articulation is independent of the testing crew since it assumes perfect callers and listeners. It can be obtained in the following way.

On page 174 it was shown that the value of sound articulation measured on a circuit by a given set of observers was related to the ideal sound articulation by the expression

$$D = D_e \times D_i,$$

where D is the actual average sound articulation obtained by a given testing crew,

D_i is the ideal sound articulation assuming perfect observers,

and D_e is the average enunciation for the given testing crew.

Suppose that it be required to determine the ideal sound articulation for a certain circuit by means of measurements of articulation carried out by a given testing crew. When this testing crew measures articulation on the given circuit, they obtain the value of sound articulation D, so that in order to obtain the value of ideal sound articulation D_i it is necessary to divide D by the value of D_e, the average enunciation for the testing crew. Now the average enunciation of the testing crew is defined as the average value of articulation that they would obtain over an ideal circuit. This value can therefore be obtained by calibrating the testing crew by means of a series of articulation tests on the ideal circuit, which we will consider as the standard reference circuit. An alternative would be to dispense with a telephone circuit and to make the calibration test in a sound proof room, free from echoes.

The complete process is, therefore, as follows:

(i) Calibrate the testing crew on the standard reference circuit and so obtain their average enunciation.
(ii) Measure, by means of this same testing crew the articulation for the given circuit.
(iii) Divide the articulation, as measured, by the average enunciation of the testing crew and so obtain the ideal sound articulation for the given circuit.

Once this value of ideal sound articulation has been obtained, the corresponding value of time efficiency can be obtained by applying the formulæ already developed.

This quantity, the ideal sound articulation, thus fulfils all the desired conditions, i.e., it is fundamental, capable of exact definition, reasonably independent of observers and testing technique, is easily measured, can be related to the corresponding value of time efficiency, and results taken in one country are comparable with results taken in other countries.

Since it seems impossible to devise any one quantity which shall satisfy both the condition that it shall be a true criterion of the circuit efficiency and the conditions just set out in connection with guarantees and specifications, it is suggested that two quantities should be used in the following way.

Standardise the ideal sound articulation as the quantity for the purpose of measurements, guarantees and specifications and all other purposes where the quantity need not be a true criterion of the circuit efficiency, and then convert the ideal sound articulation to time efficiency when a true criterion of circuit efficiency is required.

Since the most logical value of time efficiency to use is the value to be obtained for the average subscriber, it is suggested that standard curves should be got out for the different languages giving the relation between ideal sound articulation and time efficiency for the average subscriber. These curves could be calculated once and for all from the formulæ given here after adjusting the various constants to suit the case of the average subscriber.

The procedure to be followed in determining the transmission quality of a given circuit, or the effect on the quality of any change in a given circuit, would then be as follows.

Measure the sound articulation by means of a testing crew whose value of average enunciation has previously been obtained. Calculate the ideal sound articulation from the measured sound articulation and the known value of enunciation for the crew.

Then from the standard curves determine the corresponding value of time efficiency.

COMPARISON OF DIFFERENT LANGUAGES

When a telephone circuit passes between two different countries it is usual to standardise the language of one of the countries as the operating language, and all conversation between the operators in the two countries is then carried out in that language.

For this reason it is of interest to see whether the theory indicates that there is any reason for choosing one language rather than another.

The curves of Fig. 5 show that the ideal intelligibility is different for the four languages. These languages, arranged in order of their intelligibility, are for the higher values of intelligibility, Italian (the highest value), German, English and French.

In general, it can be said that the greater the average number of sounds in the words of a language, the higher will be the intelligibility. This is because a language composed of short words will have more words which differ by only one or two sounds than in the case of a language with long words. The smaller the number of sounds by which two words differ, the greater the probability of mistaking one word for another.

From the point of view of intelligibility, therefore, Italian or German would be the best language to use, since less repetition would be required in these languages than in the other two.

There is another consideration, however, which must be taken into account in this connection.

If the average time taken to pronounce a sound is b, then a word of n sounds will require a time of nb for pronunciation, and the average time taken to pronounce a word will be $1/100\ \Sigma pnb$, where p is the percentage number of words of n sounds in speech.

Taking b as unity in order to simplify the expression, the following values for the expression $1/100\ \Sigma pnb$ are obtained for the four languages.

Italian	3.9
German	3.5
English	2.8
French	2.7

The time efficiency T is the ratio of the time taken to call a given number of ideas over the ideal circuit to the time taken to call them over a given circuit, and the time taken to call a word is proportional to the number given above. From this it follows that, neglecting the time interval between words which is small, the actual time taken to call a given number of ideas over a circuit will be proportional to the value obtained by dividing the numbers given above by the time efficiency.

Taking the case of a circuit giving an ideal sound articulation of 70%, the following values of time efficiency are obtained from Fig. 5.

Italian	97.2%
German	96.5%
English	94.0%
French	93.0%

Dividing the first numbers by the time efficiencies and multiplying by 100, the following values are obtained.

English	2.98
French	2.90
German	3.63
Italian	4.01

These figures show that the actual time required to transmit a given number of ideas over a telephone circuit is smallest for French and greatest for Italian. In spite of the better intelligibility obtained for Italian or German, therefore, it is preferable to use a language like French or English. In other words, it is quicker to speak a language of short words and have to repeat some of the sentences due to the low intelligibility, than to speak a language with long words which has a relatively high intelligibility.

Conclusions

The formulæ developed in this paper from theoretical considerations enable the relation between the sound articulation, syllable articulation, word articulation, intelligibility and time efficiency to be determined for any languge, and therefore make it possible to compare values of these quantities which have been obtained under different conditions of testing technique. These formulæ contain certain constants which can be evaluated from a purely theoretical study of the language in question, without necessitating the making of any articulation, intelligibility or other tests.

It has been impossible to give an entirely rigid proof of these formulæ, since they are based on a number of fundamental assumptions as to the psychological processes that take place in the minds of the operators when participating in an articulation or intelligibility test; these assumptions, although reasonable, cannot be justified by any direct proof.

In addition, no account has been taken of factors such as intonation, accent and the duration of vowel sounds.

The agreement between measured and calculated results is so close, however, as to leave no doubt as to the applicability of the theory in those cases where a comparison has been made.

Few results of articulation and intelligibility tests have been published, so that the checks which could be made, especially in the case of intelligibility tests, have of necessity been limited. It is hoped, therefore, that further results of this nature will be made public so that a more complete check of the theory can be made, together with such extensions and modifications in the theory as may be necessary. In this connection, too much stress cannot be laid on the necessity of giving very full details of the testing technique employed in obtaining any given data, since, without this, the results may be useless or even entirely misleading.

From the study of the various quantities available as a measure of the transmission quality of a telephone circuit, it has been found impossible to choose one single quantity that will fulfil all the desired conditions.

Two quantities have, therefore, been suggested for practical use. These are the ideal sound articulation and the time efficiency.

The ideal sound articulation is chosen because it admits of simple definition and can be easily measured by a testing crew which has been calibrated on a standard reference circuit in the way described in the section headed *Choice of Quantity for the Measure of Transmission Quality.* Guarantees and specifications could therefore be drawn up in terms of this quantity without difficulty.

The time efficiency has been chosen because it is a true criterion of the transmission quality of the circuit. By means of the formulæ given under *Articulation and Intelligibility* and under *Intelligibility and Time Efficiency,* standard curves can be drawn up giving the relation between the ideal sound articulation and the time efficiency for different languages, so that, once a value of ideal sound articulation has been measured, it can at once be related to the time efficiency in order to study the quality of the transmission.

In conclusion, the author would like to thank Miss D. Hauff and Mr. T. B. D. Terroni for assistance in evaluating the many constants involved in the theory.

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List of Symbols

The following is a list of the principal symbols used in this paper:

D = Percentage sound articulation.
d = Probability of receiving a sound correctly.
S = Percentage syllable articulation.
s = Probability of receiving a syllable correctly.
W = Percentage word articulation.
w = Probability of receiving a word correctly.
N = Number of possible syllables that can be received when a given syllable is called.
M = Number of possible words that can be received when a given word is called.
$k = \dfrac{M-1}{N-1}$
V = Percentage key word articulation.
m = Average number of key words per sentence.
h = Ratio of the number of arrangements of m key words, which convey an idea, to the total possible number of such arrangements.
I = Percentage idea intelligibility.
k_n = Ratio of the number of words of n sounds to the total number of possible arrangements of n sounds.
W_n = Percentage articulation for words of n sounds.
p_n = Percentage frequency of occurrence of words of n sounds in speech.
D_n = Percentage normal sound articulation for syllables of n sounds.
t = Time required to call a single idea.
A = Number of ideas to be conveyed over a telephone circuit.
t' = Time required to transmit the A ideas over the given telephone circuit.
T = Percentage time efficiency.
D_e = Percentage sound enunciation.
D_i = Percentage ideal sound articulation.
r = Number of sounds in a prefix or suffix.
q = Ratio of number of words known by a foreigner to total number for a language.
q' = Ratio of number of words known by a foreigner to total number for speech.
v = Ratio of average sound articulation of a foreigner to that of the native.
V' = Percentage key word articulation for a foreigner.
I' = Percentage idea intelligibility for a foreigner.
W'_n = Percentage articulation for words of n sounds for a foreigner.

* * *

The Bologna Rotary Automatic Exchange

By CARL CHAPPERON

Technical Director, Standard Elettrica Italiana

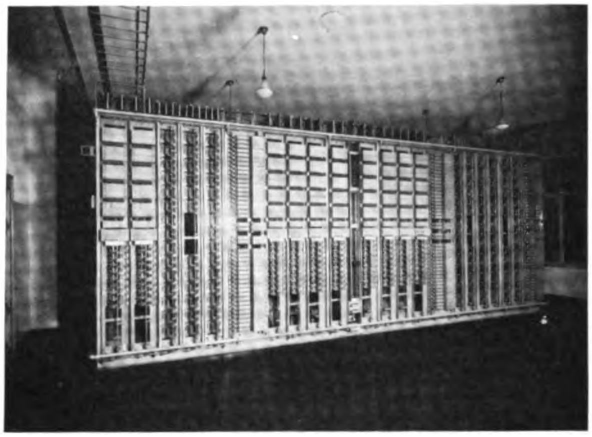
SINCE the passage of the urban telephone services from Government to private control, a change decided on by the Fascist Government and made effective on July 1, 1925, Italy has been making rapid strides towards the improvement of its telephone communications. The five Concessionaire Companies which are now operating the local systems of the country have all more or less done their share toward renewing the telephone installations of the larger cities, with the result that cities with a population of 100,000 and upward all have, or shortly will have, full automatic telephone plants.

The Rotary Automatic System, notwithstanding very keen competition on the part of the various telephone industries of other countries, has gained territory in Italy. To date, three of the five Concessionaire Companies have adopted it for some of their important cities. In Naples, the territory of the fifth Concessionaire Company, a Rotary Automatic exchange has been in operation for several years.

The most important installation undertaken by the Standard Elettrica Italiana, both as regards the number of lines and the features of the service, is that of Bologna. This city dates back beyond the Etruscan or Roman period and is still one of the most important cities in Italy. It possesses a university which was founded in the year 1000 A.D. In honour of its antiquity as a seat of learning, Bologna was selected for the recent International Congress of Mathematics.

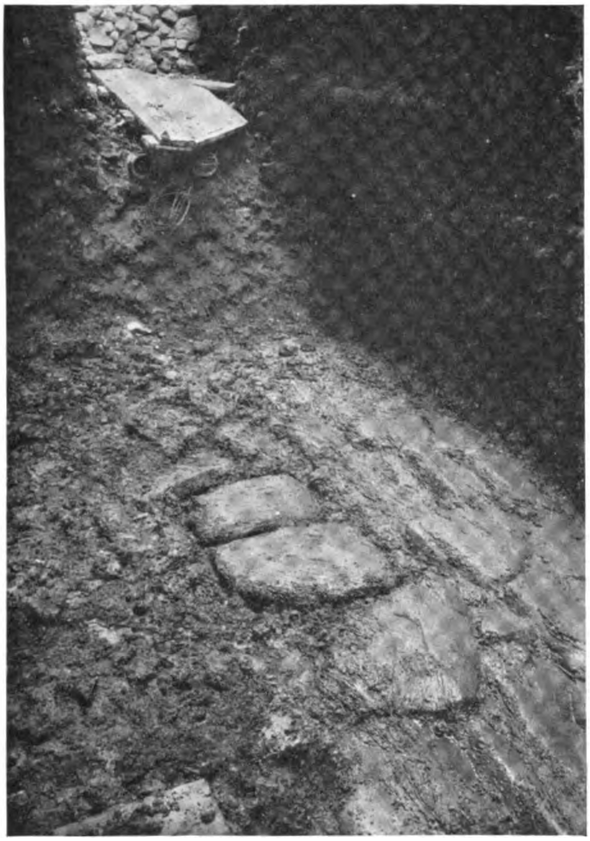
Bologna numbers upwards of 200,000 inhabitants. There are only about 4,000 telephone subscribers but with the introduction of the automatic system the Concessionaire Company expects to increase this number and use all of the 6,600 lines of telephone equipment supplied and distributed as follows: Main Exchange, 6,000 lines; Galliera Sub-exchange, 500 lines; Casalecchio Satellite, 100 lines.

The system installed at Bologna represents the latest Rotary Automatic developments and includes the automatic toll switching system, which is thus introduced into Italy for the first time. The toll exchange was manufactured and installed by the Standard Elettrica Italiana simultaneously with the automatic equipment. The toll exchange is destined to play an important part in the telephone system of the country inasmuch as Bologna is the connecting centre of the two branches, North and South, of the National Underground Long Distance Cable which is being engineered by the International Standard Electric Corporation and laid by the S.I.R.T.I. (Societa Italiana Reti Telefoniche Interurbane) with the help of the Standard Elettrica Italiana. The toll office, which will serve both the Concessionaire Company's and the State Administration's long distance lines, is composed of 14 sections with 28 operators' positions having 112 toll lines and 120 suburban lines. In addition to arrangements for the application of the pneumatic ticket distributing system, the positions are equipped with calculagraphs and key sets for the direct calling of local subscribers. By means of a special switchboard, called the *Segreteria*, subscribers can book seats at theatres, call for information regarding the arrivals and departures of trains, sporting news, etc. A special taxi-cab call service is also provided.



Bologna Central Office Switching Equipment

Bologna was the first city in Italy to be com-



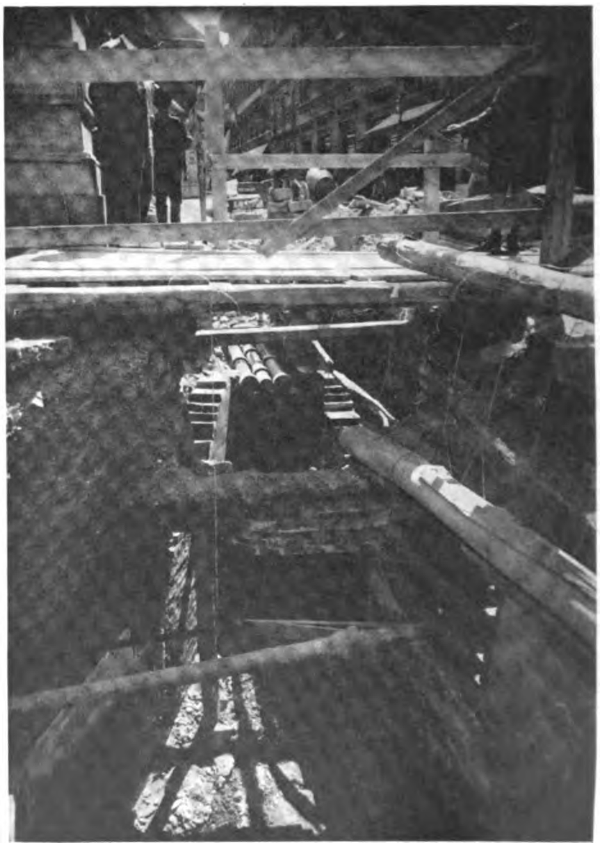
Traces of the Old Roman Road Found at a Depth of 3 Meters from the Level of the Actual Street while Digging a Manhole

pletely supplied by the same Company with all the necessary equipment for the installation of its telephone plant. The Standard Elettrica Italiana, besides having supplied the urban and toll exchanges and the subscribers' sets, also was concerned with the outside plant network which was equipped with apparatus (distributing boxes, protection boxes, junction boxes) manufactured by it and installed under sub-contract by a specialized organization, the STELLA (Societa Telefonica Elettrica Ligure Lombarda Anonima). The laying of the underground cables often presented particular difficulties because of the frequent obstacles which the Company had to surmount, such as the foundations of towers and fortresses built in the medieval era, the walls of which in some points measured ten meters in thickness. Frequently a few meters under the level of the present streets, characteristic blocks of stones comprised in the old Roman roads were encountered.

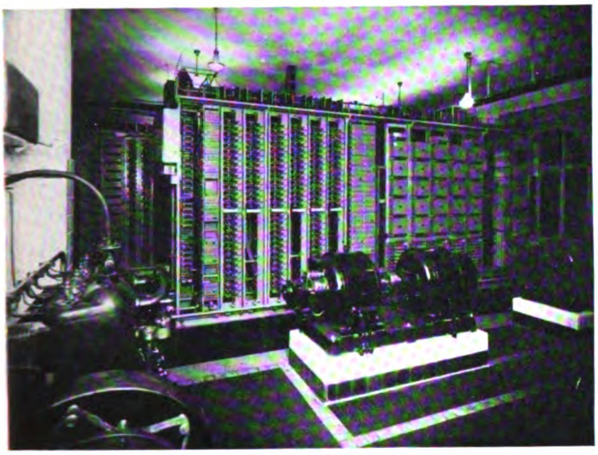
In order to arrange for the simultaneous transfer, without interruption to the service, of all subscribers from the old manual to the automatic system, ten cables were laid through a 2 m. x 1.50 manhole for providing connections between the old and the new distributing frames and a temporary main frame in parallel with the new automatic exchange was constructed. At the appointed time by means of a single cutting operation the subscribers were passed quickly from the old to the new exchange.

The exchange was inaugurated by His Majesty the King of Italy on June 12, 1928. His Majesty arrived at 3 P.M. at the headquarters of the Concessionaire Company where the exchange is installed, and after having listened to a brief speech of welcome by the President of the Company, proceeded to visit the exchange.

In the room containing the switchracks a ribbon of the national colours was tied between two selector armatures. At one of the extremities of the tape, Eng. Ricci (Technical Director



Example of the Underground Complications of the Old City of the Concessionaire Company) and Messrs. Clayton and Chapperon (Standard Elettrica Italiana) were stationed.



Automatic Exchange and Power Room

An electric button placed behind these three men and within their reach was connected to a bell installed in the power room. When the tape was cut the signal for current was sent to the power board operator and the equipment was in motion.

When the King entered the hall, followed by representatives of the Government, the President of the Concessionaire Company, Count Isolani, and the Managing Director Hon. Ponti, also Messrs. Clayton, Chapperon and Ricci, were presented to His Majesty. After the work had been blessed by the Cardinal, His Majesty immediately proceeded with the inauguration by the symbolic cutting of the tape. His Majesty was pleasantly surprised and impressed at the immediate operation of the machines and congratulated the representatives of both the Concessionaire Company and the Standard Elettrica Italiana. Since the visit to the exchange lasted approximately 30 minutes, His Majesty and the representatives of the Government accompanying him were enabled to call for explanations with reference to the operation of the equipment.

Toll Office—Telefoni Italia Medio Orientale, Bologna

International Telephony

By F. GILL

Vice President, International Telephone and Telegraph Corporation

IN January, 1923, over $5\frac{1}{2}$ years ago, I spoke before the Post Office Telephone and Telegraph Society of London on, among other things, the urgent need for a new outlook on long distance telephone service in Europe. Since then there has been a very radical change in this service.

Let us begin our historical review by seeing what happened in this service between England and other places overseas. Figure 1 begins with service opened with France in 1891; 12 years later in 1903 came service with Belgium; 11 years later in 1914 service with Switzerland began, and in 8 years more (which included the War years), in 1922, came service with Holland.

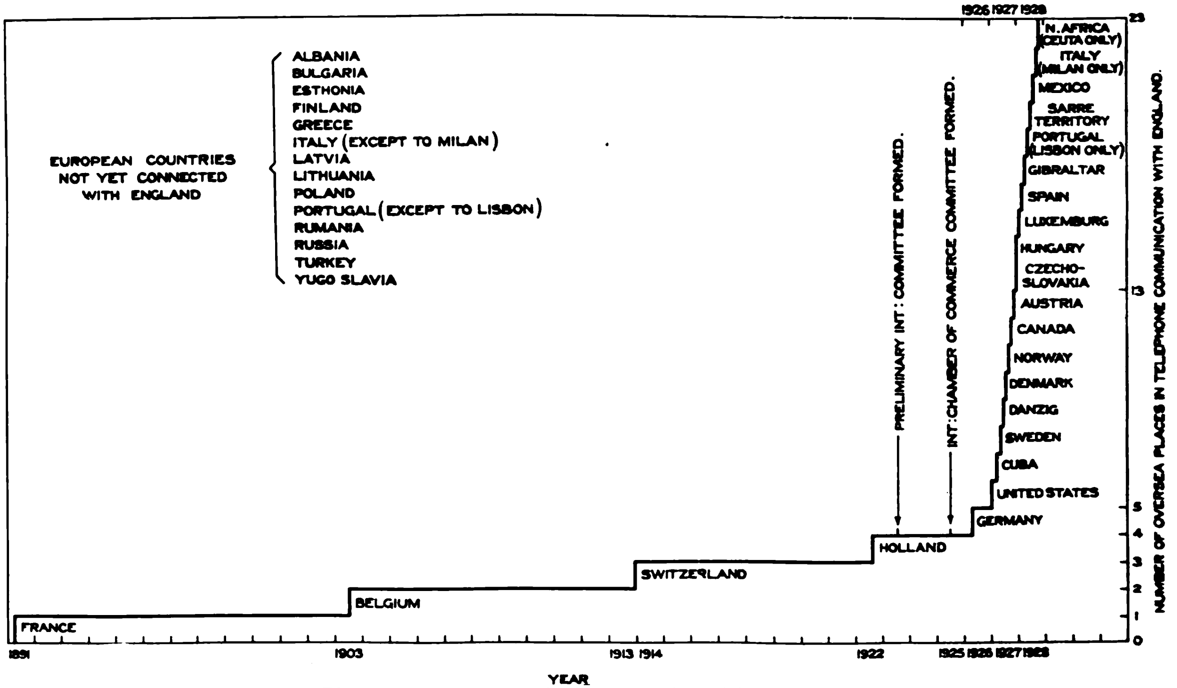


Figure 1—Overseas Telephone Service with England

Then in 1923 the French Telephone Administration took a very momentous step. It called together a Preliminary Committee to consider what should be done to make better provision for dealing with the International service. As a result of this meeting the C.C.I. (Telephones) was formed in 1924; the first President was the late M. Denery, succeeded, on his untimely decease, by another Frenchman, M. Milon. The Secretary-General throughout has been M. Valensi. In assessing the good work which has been done by the C.C.I. this special contribution by France should not be forgotten.

In 1926 service with Germany began. In the next year, 1927, 5 services to Europe and 3 to North America [2] were opened, and in the present year, 8 places in Europe, 1 in North America [2] and 1 in Africa, were opened.

We have therefore, between 1891 and 1923, 32 years producing 4 services; since 1923, $5\frac{3}{4}$ years producing 15 services in or through Europe, as well as 4 in North America.

Figure 2 shows the extent of the service between England and the Continent at October 1, 1928.

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[1] A paper read before the Post Office Telephone and Telegraph Society of London, October 15, 1928, and reprinted from the *Telegraph and Telephone Journal.*

[2] The American Services were developed apart from the C.C.I.

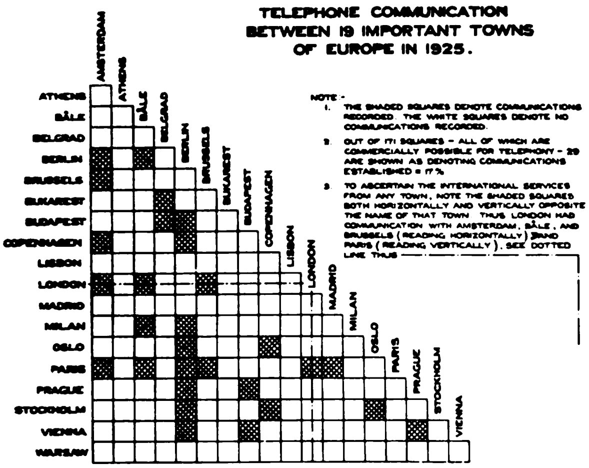
TELEPHONE COMMUNICATION BETWEEN 19 IMPORTANT TOWNS OF EUROPE IN 1925.
NOTE:-
1. THE SHADED SQUARES DENOTE COMMUNICATIONS RECORDED. THE WHITE SQUARES DENOTE NO COMMUNICATIONS RECORDED.
2. OUT OF 171 SQUARES – ALL OF WHICH ARE COMMERCIALLY POSSIBLE FOR TELEPHONY – 29 ARE SHOWN AS DENOTING COMMUNICATIONS ESTABLISHED = 17%
3. TO ASCERTAIN THE INTERNATIONAL SERVICES FROM ANY TOWN, NOTE THE SHADED SQUARES BOTH HORIZONTALLY AND VERTICALLY OPPOSITE THE NAME OF THAT TOWN. THUS LONDON HAD COMMUNICATION WITH AMSTERDAM, BÂLE, AND BRUSSELS (READING HORIZONTALLY) AND PARIS (READING VERTICALLY). SEE DOTTED LINE THUS
AMSTERDAM
ATHENS
BÂLE
BELGRAD
BERLIN
BRUSSELS
BUKAREST
BUDAPEST
COPENHAGEN
LISBON
LONDON
MADRID
MILAN
OSLO
PARIS
PRAGUE
STOCKHOLM
VIENNA
WARSAW

Figure 3

To illustrate to myself and others in a rough and ready fashion the progress taking place, I have been accustomed to consider the service between a number of capital and other cities in Europe, the number of cities being 19. It is obvious that the total number of possible services is $\frac{19 \times 18}{2} = 171$. At the end of 1922, before the C.C.I. was formed, there were 28 of these services, equaling 16.4 percent, and of these 28, only 6 involved an intermediate or transit country—all the other 21 were between contiguous countries.

1 of these 19 towns had 10 connections.
1 " " " " " 6 "
4 " " " " " 4 "
6 " " " " " 3 "
2 " " " " " 2 "
2 " " " " " 1 "
3 " " " " " No "

By 1925 the number of services to other countries had increased by 1 and was then 29 out of the 171, or 17 percent. (See Figure 3.[3])

But by May 1928, the work of the C.C.I. had become apparent; the number of these services had grown to 87 out of the 171, or 50.9 percent, and by October 1, 1928, as shown in Figure 4,[3] the number had increased to 98 or 57.3 percent.

A great advance has been made in the degree of transmission given over the International lines; speech which was previously difficult and unsatisfactory has, in very many cases, become easy and the improvements continue as from time to time new areas of local territories are admitted to the International System.

Another advance which should be mentioned is the reduction in the time elapsing between the ordering of a call and commencement of conversation. Here are some C.C.I. records of average delays in minutes, during busy hours:

	1925	1927	Last Quarter of 1927, the Latest Record Available
Berlin–Paris	130	68	34
Berlin–Vienna	143	62	43
Berlin–Stockholm	89	39	30
London–Amsterdam	61	34	32
London–Brussels	31	19	8
Paris–Brussels	180	180	100
Paris–Turin	180	10	10
Stockholm–Copenhagen	8	8	13

But lest it should be thought that all delays are no longer than those shown in the third column, let me say that in the last records there are many cases of average delays in busy hours of 60 minutes and over.

Another advance lies in the changes in service offered, e.g.,

Charging for each minute after 3 minutes instead of by units of 3 minutes.

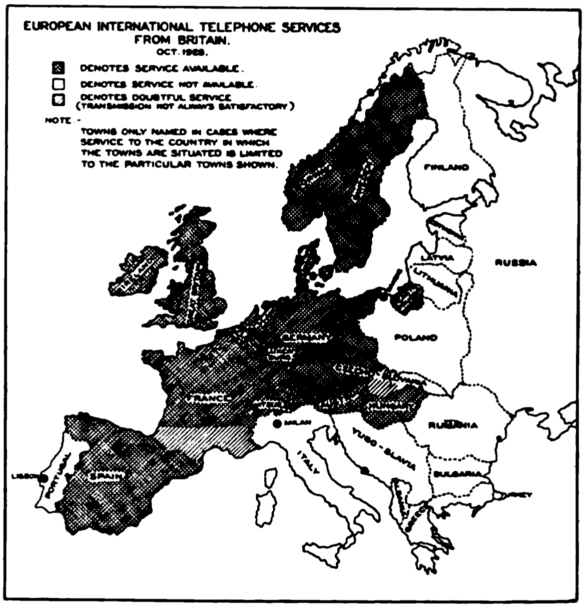
EUROPEAN INTERNATIONAL TELEPHONE SERVICES FROM BRITAIN.
OCT. 1928.
▨ DENOTES SERVICE AVAILABLE.
☐ DENOTES SERVICE NOT AVAILABLE.
▧ DENOTES DOUBTFUL SERVICE (TRANSMISSION NOT ALWAYS SATISFACTORY)
NOTE:-
TOWNS ONLY NAMED IN CASES WHERE SERVICE TO THE COUNTRY IN WHICH THE TOWNS ARE SITUATED IS LIMITED TO THE PARTICULAR TOWNS SHOWN.
FINLAND
LATVIA
RUSSIA
POLAND
FRANCE
MILAN
RUMANIA
ITALY
JUGO-SLAVIA
BULGARIA
TURKEY
LISBON
PORTUGAL
SPAIN

Figure 2

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[3] These diagrams are the copyright of the International Chamber of Commerce, to whom acknowledgment is made for their reproduction here.

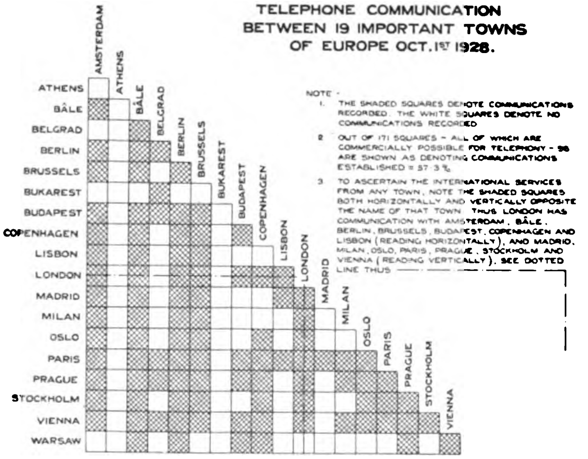

Figure 4

Fixed time and subscription calls made available. "Notice" (préavis) calls have been introduced.

It is sometimes said that Toll Cables and Repeaters were developed during the War and that, of course, the instrumentalities available were very different after the War. Of course, that is true, but it is not the explanation of the lack of service at the beginning of 1923.

For years, overhead bare wires had been the recognized means of transmitting speech; the London–Paris circuit, involving a submarine cable, had been in operation since 1891, 32 years. The New York–Chicago circuit, 1187 kms. long (736 miles), had been in operation since 1892. It is true that it is easier and more economical to give service now with our present facilities, but the real explanation for the lack of long distance service in Europe was the absence of any organization to deal with it.

Thus far we have great encouragement from the relatively rapid advance made recently, and we may well stop for a moment to acknowledge all that the C.C.I. has achieved and to express admiration and gratitude in respect of its work.

But while according our full admiration perhaps we shall do best to leave, for the moment, the things which are behind us and fix attention rather on the things which are in front and remain to be done. We must not forget that all these places are within easy telephonic reach of each other, that they are capital (or equivalent) cities of the countries and that the history has shown that traffic is all the time waiting for facilities.

There still remain, after $5\frac{3}{4}$ years, about 42 percent of these cities without connection with each other. There still remain some cities which are very badly served by International connections. Perhaps there will still remain, when all these 19 cities are taken care of, other important cities in Europe not connected, and there will certainly be places just outside Europe still unconnected. Obviously, therefore, it is not yet time for a folding of the hands, nor for contentment with what has been accomplished.

Figure 5 shows a map of 1922; it shows some United States Long Lines then in everyday use projected on the map of Europe. To-day the longest line (practical crow-fly measurement), between International Toll terminating centers in public service is Lisbon to Berlin, about 2,310 kms. (1,430 miles). Although this length could be extended by considering the full distance covered between subscriber and subscriber, yet Europe of 1928 is still a long way behind the United States of 1922.

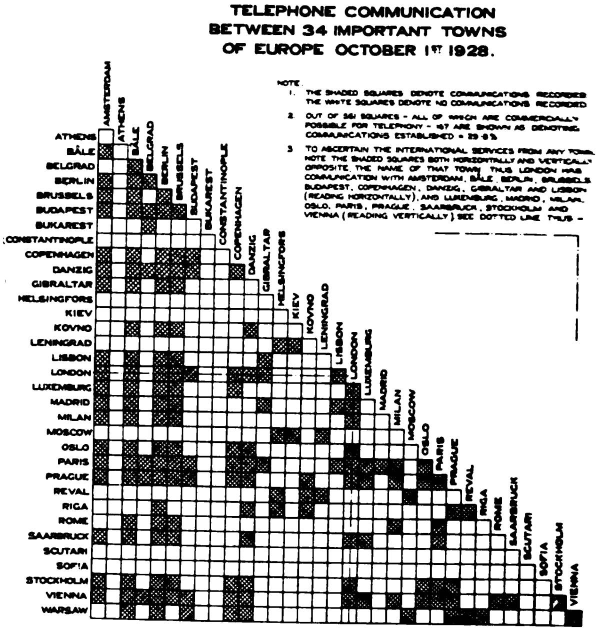

Figure 6

The time has come to extend our 19 cities. Figure 6 gives the list extended to 34 towns; none of these can be dismissed as fantastic. The services which are now in operation, so far as I am aware of them, are shown shaded and the extent which they are available to the public is 29.8 percent at October 1, 1928.

Towards the extension of service to these places, there were completed in Europe in 1927 5,000 kms. (3,100 miles) of toll cable. The most notable cases were Austria, nearly 800 kms., France over 1,000 kms., Belgium 460 kms. and Germany about 1,000 kms.

The International Chamber of Commerce

We have spoken of the C.C.I. Telephones; there is another factor which should be mentioned, the International Chamber of Commerce, which first took up the question at Brussels in 1925 and has throughout operated with the full knowledge of the C.C.I., whose Secretary General attends the meetings of the I.C.C. International Telephone Committee and who has been very good in supplying information. The International Chamber of Commerce has placed on record its ideas of the importance of International Telephony, and the same applies to National service as well. The Report of the Stockholm Congress in 1927 states:

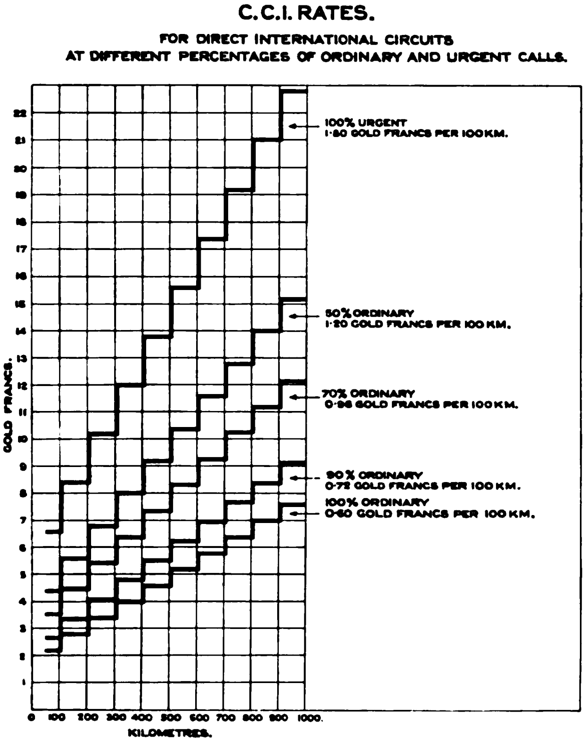

Figure 7

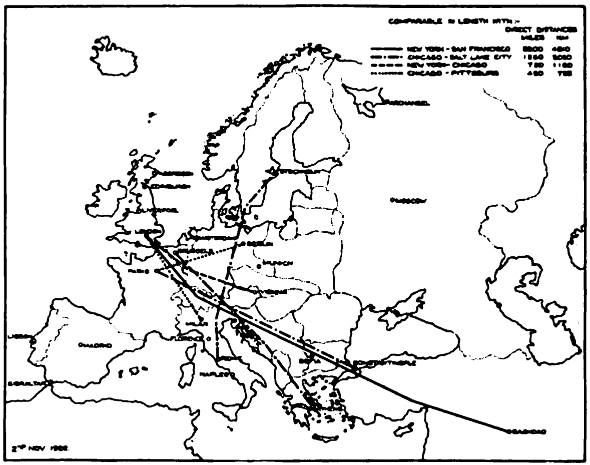

Figure 5—Some United States Long Lines Projected on the Map of Europe

THE IMPORTANCE OF INTERNATIONAL TELEPHONY

In the consideration of the subject by the Committee they early developed a growing realization of the importance of international telephone service.

(*a*) As an effective instrumentality for removing impediments to international trade, and

(*b*) That the ability to secure speedy personal communication between distant cities should be a factor in stabilizing business through a more orderly and economic movement of goods.

(*c*) That effective telephone service tends to facilitate all the processes of production and distribution.

(*d*) That ability to communicate information quickly, tends to minimize the range of price fluctuations and thereby lessen the tendency to speculation.

(*e*) That any instrumentality which tends to stabilize business, facilitate its processes, and effectively extend the field of operations with consequent increase in the volume of trade, should lessen the difficulties of international settlements, as after all, all settlements have to be made ultimately in goods or services.

(*f*) That the ability to communicate voice-to-voice, easily and speedily, whenever desired or needed, cannot but be a means of improving social relationships and developing a common economic and social viewpoint which inevitably must have an effect in promoting a better understanding between nations.

In the meetings of this Committee it has been particularly noticeable that what the business men desired as expressed in the report presented at the Stockholm Congress in July, 1927, was:

> Uniform, dependable, fast service with good audition between all important trading centers in Europe.

Is not that an eminently reasonable request, in keeping with your own ideals? When we couple with that the numerous evidences of rapidly increasing traffic, is it not a worth-while job to follow energetically the development of this Long Distance Service? In the year 1926/27 nearly 37 percent of the small surplus made by the British Telephone System came from the Continental Telephone service, and it seems a fair assumption that this service is a profitable one, as indeed it should be.

Let us now look further to the future and to some of the things which apparently require attention.

Partial Service

There are still some places which are connected with each other for less than the complete 24 hours of the day. In some other instances connections are set up every alternate half hour to produce direct trunks, thus producing the effect that there is only connection between *A* and *B* during each alternate half hour and between *A* and *C* during the other alternate half hours. This produces long delays.

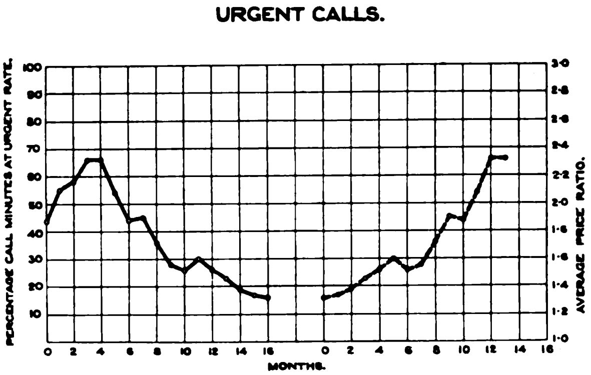

Figure 8

Toll Rate Principles

There are two entirely different foundations for the toll rates in force in Europe. There is no difference in the degree of transmission afforded, and the two may be stated in condensed form thus:

A. Service is given at as cheap a rate as possible, this rate being termed "Ordinary." Ordinary calls should habitually experience a delay of not more than 30, 60 or 90 minutes, according to the length of the circuit. Calls may be ordered to be "Urgent" at triple ordinary rates, or to be very fast, "Lightning," at 10 times ordinary rates. Equipment is not intended to be provided to meet busy hour loads, but is to be provided on the basis of the load spread out by reason of the delays permitted. Cheaper rates are in force in times of light traffic.

B. All calls are of equal urgency and pay the same rate, called here the "Day" rates. A fast service with a delay not exceeding, say, 10 minutes, is aimed at. Equipment is provided to meet the busy hour load. Cheaper rates are in force in times of light traffic.

As would be expected, plan *A* leads to more calls per line per day, longer delays and a cheaper "Ordinary" rate. Plan *B* leads to fewer calls per line per day, a faster service and a "Day" rate which is dearer than the "Ordinary" rate under plan *A*.

But, obviously, the "Ordinary" rate may not be the rate paid by an individual, nor yet the average rate; this latter will depend upon the proportions of ordinary, urgent, and lightning calls.

To contrast the "Ordinary" Rates, plan *A*, with the "Day" Rates, plan *B*, is obviously misleading, yet it is constantly being done. Take a case of, say, between 700 and 800 kms.; at C.C.I. ordinary rates, the price is 6.4 gold francs. Against this take the London–Zurich day rate, 10.0 gold francs (about the same distance but including a submarine cable). But if we assume that out of 100 calls, 87 are ordinary, 12 are urgent and 1 is lightning, then the average C.C.I. rate would be 8.51 gold francs, leaving 1.49 gold francs for the submarine cable of the London–Zurich circuit.

Or take the case where the ordinary calls are only 34 percent, the rest being at triple rates; the average price for 800 kms. at C.C.I. Rates would then be 14.85 gold francs.

Figure 7 illustrates the C.C.I. Toll Rates as they vary in accordance with the proportion of Urgent calls.

Figure 8 illustrates a published case; over a period of 16 months the percentage of call minutes at urgent rate rose from 45 percent to 66 percent and then fell to 16 percent, with a consequential great drop in revenue owing to the heavy falling off in calls bringing in threefold fees, a loss not compensated for by general increase in toll traffic. The cause of the fall in urgent fees was that more trunks had been added and owing to a faster service, due to these additional facilities, there was less need to pay triple rates.

The right hand part is the same curve reversed. I have assumed it is fair not only to consider what happens when the proportion of urgent fees falls off, but also when it increases. It increases because of congestion; subscribers making calls and suffering delays endeavor to mitigate their trouble by placing urgent orders. The scale at the right hand shows the average price ratio, assuming no lightning calls; in this assumption the average price ratio increases from 1.32 to 2.32, an increase of 76 percent. Is this likely to give satisfaction to the subscribers? Will they not examine their bills and feel that their calls are costing much more? Then when more trunks are added, as they must be, is not the Telephone Authority in a dilemma? If it improves the speed it may involve (in the case quoted it *did* involve) a loss in total revenue while, at the same time, it increases expenses.

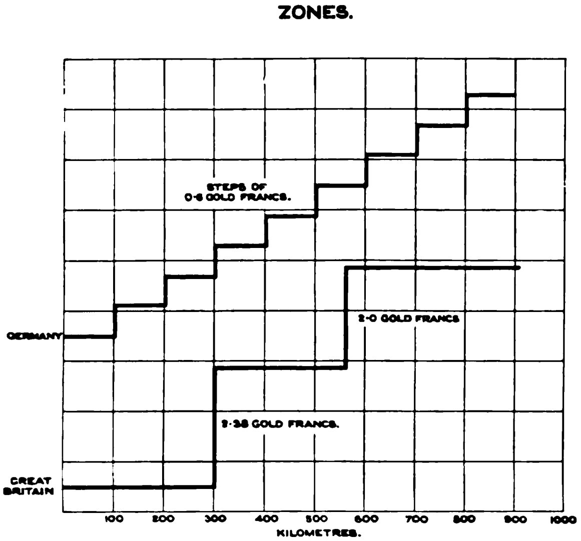

Figure 9

One wonders—Can there be a real place for lightning calls at 10 times the "ordinary" fee? If an urgent call at triple fee matures in *reasonable* time, it would seem unlikely that the speed could be so increased as to make a tenfold fee attractive; or conversely, if the tenfold fee calls are made, is it not rather because the urgent calls are much delayed and the ordinary calls are impossible? There are cases where the urgent calls over the whole day are about 70 percent of the total; probably that means that all the calls in the busy hours are urgent at triple rates. In some cases a lightning call passes out of that category into an urgent call if it does not mature in 15 minutes.

When it is found that the public pays a triple fee to reduce somewhat the average delays, is not that evidence that they are willing to back up your efforts to supply first class service? Here are some figures of these delays:

EXAMPLES OF AVERAGE DELAYS IN MINUTES, ORDINARY AND URGENT, ON THE SAME CIRCUITS IN BUSY HOURS, 1927. C.C.I. RECORDS

On Ordinary Calls	On Urgent Calls	% of Urgent Calls
20	8	10.0
13	6	2.4
16	9	4.5
71	41	12.5
18	5	1.8
38	17	not shown
41	28	
33	13	
90	36	
120	48	

All these points rather suggest that these special rates are founded upon old-time inadequate facilities, and will have to be abandoned in modern systems.

It is usual in Europe to consider the Toll Rates in the United States as altogether too high for Europe. But is that so, if we compare like with like, or as near as may be? In the A. T. & T. Report for the year 1927 it was stated:

> The average length of time for handling a toll call in the Bell System was reduced from 2 minutes in 1926 to 1½ minutes in 1927. About 90 percent of all toll calls are now handled while the subscriber remains at the telephone, as compared with 80 percent a year ago.

Take a case of a call between places, say, 1,430 kms. (890 miles) apart, and assume as near as may be similar service.

The Bell Long Distance Rate for Person to

Person service would be 23.40 gold francs for a 3-minute call.

The C.C.I. Lightning Rate on direct trunk would be 100 gold francs for a 3-minute call. It is doubtful if the delay would be any less than the delay on the Bell System, and the service would be inferior, in that no Particular Person Service would be afforded and the individuals required would have to be sought after communication was established, which might increase the fee. The reason why no Préavis call is assumed in this case is that with the very fast call there would be no time in which to send the preliminary notice.

The C.C.I. Urgent Rate, with Préavis fee would be 33.30 gold francs for a 3-minute call. The delay would almost certainly be considerably more than in the Bell System call.

But comparing rates in different countries by merely converting the currencies is liable to be misleading, because it takes no account of the *relative* burden which the rate imposes, because that method pays no attention to the wealth of the person paying the rate. If consideration be given to this point, the United States rates are a good deal cheaper than they appear to be.

I submit that all the evidence tends to show that Europe desires a high-speed service, is willing to pay for it and that it should be possible to provide it.

Another matter in toll rates that requires unification is the various methods at present employed in zoning International calls. Figure 9 contrasts the steps which constitute a zone in Great Britain and Germany. Note, that the position of the two curves does not imply any relative price comparison.

Person to Person Service

Another service facility about which there is at present lack of uniformity is that of Person to Person calls.

Mr. Lignell of the Swedish Administration has shown that in the Swedish experience the demand for this service increases with the length of the circuit. This seems quite what would be expected. If *A* in London wants to talk to Vienna, it is likely that *A* wishes to get into communication with a definite individual, *B*, and it is probably not of much interest to *A* to talk to *B*'s office or hotel and be informed that *B* is absent. Further, the time lost in calling to the telephone the particular person whom *A* wants is a wasteful and serious inroad on the time paid for.

The Person to Person service gets rid of these objections; both the persons who are to talk are brought together at the moment of starting the time to be paid for, and the operating organization receives an enhanced fee for the additional work it has to do.

At present Europe has in places, not with England, however, a service called Préavis, which is a "sort of" person to person call. But it is not the real thing as you have it on the Transatlantic service.

There is so much unprecise use of the words "subscriber" and "line," that in considering this kind of service it seems well to pose a case and to test any service offered on this case. Assume then, a person *A* from an extension on Holborn 1234 in London wishes to talk with person *B* who will be found on an extension on Carnot 5678 in Paris. The time to be paid for is not to begin until *A* and *B* are in conversation.

The complete préavis service is made up of two calls, a preliminary notice, the Préavis, sent over the trunk and given by the incoming Trunk operator to the wanted number, to the effect that a call will shortly be coming from (in the above case) London, and that *B* will be asked for. If *B* will be ready (and for our present purpose we need not follow other variations), the call proper will mature and be treated very much in the ordinary manner. Thus the préavis is the preliminary notification, it bears a separate fee which is based upon the unit fee, and it is followed by an ordinary call. In actual service the préavis practice differs. Sweden in its connections with Norway and Denmark, puts the names of the two individuals on the ticket and when the call matures the operator gets these two persons into conversation before starting the time to be charged. But other countries do not go so far; they seem content with getting the two P.B.X's. into connection and start the time to be paid for from that moment. In fact, the actual call is an ordinary call with no precautions, except that when each of the two stations or P.B.X's. reply,

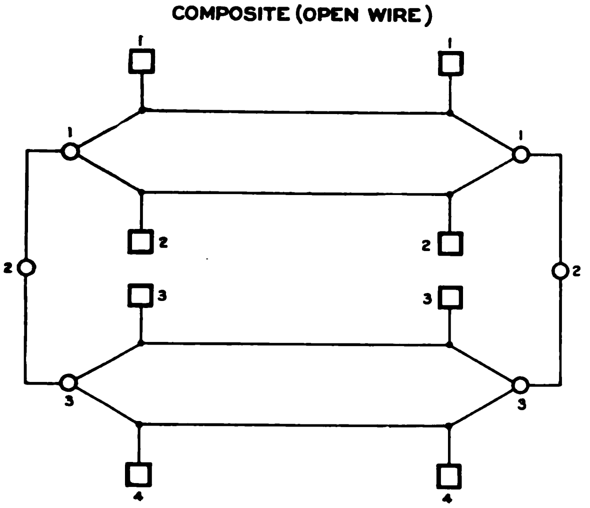

Figure 10

they are given the name of the individual wanted and the name of the distant town.

Substantially, Europe does not at present enjoy a Person to Person service[4] and with the increasing length of International lines this facility seems overdue. In considering the future of this kind of service three statements seem likely to be true:

> The longer the connection the greater the demand for Person to Person service.
>
> The greater the Person to Person service the greater the demand for speedy service.
>
> The more speedy the service the greater the likelihood of the préavis type of call being abandoned.

Unused Facilities

If we consider 4 wires giving telephone service on 2 channels, by means of suitable terminal arrangements and by proper transposition of the wires, we can make a third circuit without adding any more line wire, and the longer the line and the heavier the wires the more desirable economically does this third circuit become. In nearly all toll cables and on most open wire circuits this creation of a phantom circuit is commonly employed.

But there are other facilities which at present are unused on International lines in Europe, although they offer great attractions. The same 4 wires if of open bare wire construction can, without robbing the telephone income in any way, also provide 4 independent two-way telegraph circuits, while if in cable there may be added two independent two-way telegraph circuits.

Figure 10 shows in circles the 3 telephone rentals collectable from 4 open wires; these are very generally used. It further shows in squares the 4 telegraph revenues which may also be collected from the same wires and these last are practically neglected in Europe.

Figure 11 shows in circles the 3 telephone rentals obtained from 4 cable wires and the two telegraph rentals which are being neglected. The illustration is for 2-wire telephone circuits; the same telegraph revenues are possible if the telephone circuit is a 4-wire one.

Again, on open wires, without detriment to the ordinary telephone rentals, we can, by carrier, add three other conversations simultaneously and thus in many cases increase the income-earning power of a pair of wires from $1\frac{1}{2}$ to $4\frac{1}{2}$ and, with the 2 telegraphs, to $6\frac{1}{2}$ rentals; or on the same pair and without injury to the ordinary telephone rentals, we can add 12 two-way telegraph rentals, 10 being by carrier and two by composite apparatus. Or again, in a telephone toll cable which has spare circuits available, by giving up telephony on one pair, we can provide for 6 two-way telegraph rentals.

Now since all these arrangements are made by apparatus, it is approximately correct to say that their attractiveness increases with the length of the line, and yet surprisingly little use is made of these facilities, even though the number and length of long lines is growing rapidly. The London–Madrid circuit is one of the very few such cases within my knowledge; in this case a pair of open wires between Versailles and Zaragoza, in addition to the ordinary telephone circuit and half a phantom, carries 3 telephone carrier channels with their accompanying rentals, and it could also carry two telegraph composite circuits.

There is another case between Copenhagen and Hamburg where two extra telegraph circuits are provided by composite. I understand also that there are some voice frequency telegraphs used on International telephone circuits in France.

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[4] Since writing the above, I learned that the British Post Office has already made proposals for a real Person to Person service and I hope that its efforts will be successful.

Now more or less throughout Europe the Telegraph Departments are in financial difficulties, suffering from the competition of the telephone. Is there not in these extra facilities a means of reducing the annual cost of lines; may it not even be economical to cut down existing telegraph lines and use telegraph circuits which can be provided at little extra cost and be utilized either in the public service or leased as private wires at attractive rates? If, for example, at a cost which relatively is low, it is possible to operate 12 two-way telegraph circuits, between say, Paris and Vienna, over a four-wire telephone circuit, is it not possible, by suitably adjusting the rentals charged, to build up a profitable business by the use of these neglected facilities?

Possibly the fact that the long lines of Europe pass through more than one ownership is one reason why, apparently, no one seems to feel the urge to make the most of these long lines. Or it may be that there are difficulties in the fact that frequently there are practically two departments, the telephone and the telegraph, which have to see eye to eye before these facilities can be employed. But it does seem that full use is not being made of the money which has been expended. Perhaps this is a matter on which the C.C.I. (Telegraph) could do good work.

The Future of International Telephony in Europe

Why do we use the expression International Telephone service as if it were something special and different from ordinary Long Distance service? The answer is one of organization. In ordinary Long Distance service, the whole toll circuit and frequently both local ends are in the hands of one administration, responsible for all the arrangements and in a position to take at short notice any action it may judge necessary.

But in the International service a Toll circuit belongs to and is operated by at least two authorities; there may be several more. Each of these authorities has its own sovereign powers, its own way of doing its work, its ideals of service, technique, hours of duty, costs and manner of charging the public.

A telephone message is not like a parcel or a train, which progresses from moment to moment and does not occupy very much space at any one time. In telephony, the whole circuit is simultaneously and exclusively occupied with the one call and should be so constructed, maintained and operated, that its different sections under different controllers are harmonious and operate as one whole.

I confess that I find it a very difficult thing to imagine this harmonious working carried to a high degree of efficiency under the present system of multi-control. Of course a great deal has been, and undoubtedly in the future will be, done, but there are degrees of efficiency and it certainly seems to me that multi-control can never, with the best will in the world, produce results comparable with those given by unity of control.

The function of the C.C.I. so far, has been to form a common public opinion among the long distance telephone authorities of Europe as to certain matters, such as specifications for the construction of long lines, rules regarding maintenance and some standardization of traffic and rating matters, though these two are not as advanced as what is known as the Transmission Section. But in daily operation of the service much more than common opinion or a book of rules is required. At present no one person is in charge of general policies and decisions; no one is able to lay out new circuits which the traffic requires, nor to make definite programmes

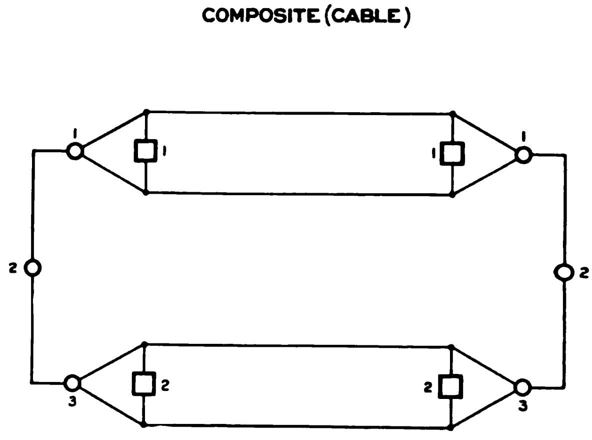

Figure 11

and budgets, nor to make schedules for carrying out works. No one can make new rates and services; all these require prolonged collaboration. No one is in charge of the maintenance; a trouble in one control area may cause great difficulties in that of another, without involving any responsibility on the first.

In ordinary business where the work of a number of people has to be closely co-ordinated to produce success, one of the ways of increasing the efficiency is by comparing the results of districts and divisions, and then devoting attention to the places thus shown to be relatively weak, by this procedure eliminating the weak points and progressively enhancing the efficiency of the strong places. This method of comparison is entirely missing at present and even if weak places were known there is no common machinery for strengthening them, nor indeed any single authority to decide what the treatment should be. Imagine the trunk service in this country if each large trunk area were independent, and if no observations, statistics or information from each of these divisions came to a single authoritative head and therefore common supervision were lacking; or imagine the maintenance of the plant handled independently by each division without any supervision or co-ordination on the part of some central authority. Imagine none of the comparisons, conferences, schools, special instruction, etc., which are employed to screw up efficiency gradually to the highest point within an organization—imagine none of these methods employed in your inland toll service and you form some picture of the International service. In maintenance such matters as studies leading to decreased cost have to be made and the lessons from these studies have to be applied. Examples are comparisons of faults, the length of time circuits are out of order, the number of times circuits are outside their specified transmission limits. In the Traffic Departments the comparison of Toll observations are important. In all these it is not the adherence to prescribed standards that is so important; it is rather the constant striving after better results assisted by comparisons between divisions which causes a progressive increase in efficiency and improvements in service, and this gradual development of technique and efficiency among very large numbers of persons is one of the very difficult jobs for many businesses.

In the absence of all these things which flow so directly from unity of control, something, of course, would be done and service would result; but it would need a miracle to give it the efficiency of a service supervised and controlled by a competent central authority.

We know that not much, if anything, is gained by increasing the size of any one organization beyond a certain extent. But the individual nations of Europe are far too small to form the economical units for this service, and I cannot escape the conclusion that, sooner or later, there will have to be found some single unit for the administration of the European International service, unless indeed Europe is to rest content with a service relatively much inferior to the plant which she has provided, and I cannot believe that will be the case.

While the first attack on this problem was concerned with physical matters and lay mainly with the engineering departments, the development which has taken place has shifted the point of attack, which now lies largely with the administrative and traffic departments. To-day the problem seems to apply mostly to business matters.

I want particularly to acknowledge the help I have received from Mr. W. J. Hilyer, in dealing with this subject.

Allocation of European Broadcast Wavelengths —Some New Points of View*

By SIFFER LEMOINE

Chief Engineer, Swedish Telegraph Administration

THE problem of the allocation of wavelengths for the broadcasting stations of Europe has for some considerable time proved a constant source of discussion and the question is, perhaps, more acute than ever at the present time.

The scheme devised at Geneva by *L'Union Internationale de Radiophonie*, which came into operation in November, 1926, and to which most of the broadcasting organisations of Europe have given their adherence, has undoubtedly proved a step in the right direction but, in spite of its defects, it cannot be regarded as representing a final solution to the problem.

Many widely divergent difficulties have hindered the successful execution of the proposals. There are countries and broadcasting organisations who have not conformed to the "Geneva Scheme" and whose stations have been continually changing their wavelengths. These have constituted what might be termed a party of "freebooters of the ether" interfering now with one and now with another of the orthodox stations with results that have naturally been of little service either to themselves or to those affected. Further confusion was also caused by the fact that a number of stations were equipped with old-fashioned installations which were unable to maintain the high degree of accuracy now deemed essential in the maintenance of a constant radio frequency and, indeed, unable to maintain even approximately the wavelengths allotted under the scheme, a difficulty which it is hoped will gradually disappear but of which the effect is at present somewhat annoying. When accurate distribution of wavelengths was first attempted this, more than any other factor, proved the greatest stumbling block, but now it can, to a certain extent, be remedied by fitting one of the wavemeters that have been constructed to meet the requirements of the Union. The need for absolute constancy of radio frequency is incontestable and should be insisted on more than has hitherto been the case either in connection with the reconstruction of old installations or in the erection of new stations.

During the past twelve months it may be said that this phase in the development of broadcasting has mainly been characterised if not by stagnation at least by a reduction in its progress as compared with former years, due to a certain doubt as to the principles on which its future is to rest and an uncertainty as to what is likely to be permissible or practicable as time goes on. Even where the Geneva Plan has been accepted it has been, in many cases, with a realisation of its imperfection in its present state and in the hope of a revision in the future.

True, some countries have, within the scope of the agreements now in force and without waiting for forthcoming international regulations, managed to increase the power of their stations, but most countries have adopted a cautious attitude, both as regards extending their power and erecting new installations, having in mind especially the question of the principles that might be laid down on this point by the International Radio Conference held at Washington last autumn.

The Resolutions passed by the Washington Conference, and their Significance

The resolutions passed by the Washington Conference are now known, although there has not yet been time to ratify them. Various wireless services have had their different wavebands allotted—including broadcasting—while the particularly vital question (from the European point of view) of wavelength rights for every country and other principles governing the use of the broadcasting bands has been left open for the present.

It may be said that the result, as far as broadcasting is concerned, has been poorer than had generally been anticipated. Those zones that have now been assigned for the purpose have been extended in so niggardly a fashion that not only has the growth of the number of stations been stunted but a restriction has been practically laid on those that were previously functioning.

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Thus, above 1,000 metres, permission has been granted in Europe to use the zone from 1,875 to 1,550 metres, corresponding to 160–194 kilocycles per second, exclusively for broadcasting and from 1,550 to 1,340 metres (194–224 kc/sec.), jointly with the air services, but with the proviso that no increase in power may take place so long as disturbances with other traffic may be caused thereby. Below 1,000 metres the limit upwards has been reduced from the present maximum of 600 metres down to 545 metres, while the lower limit has been maintained at 200 metres—corresponding to the kilocycle numbers 550 to 1,500—with the exception of 220 metres (1,365 kc/sec.), which has been allotted exclusively for maritime requirements.

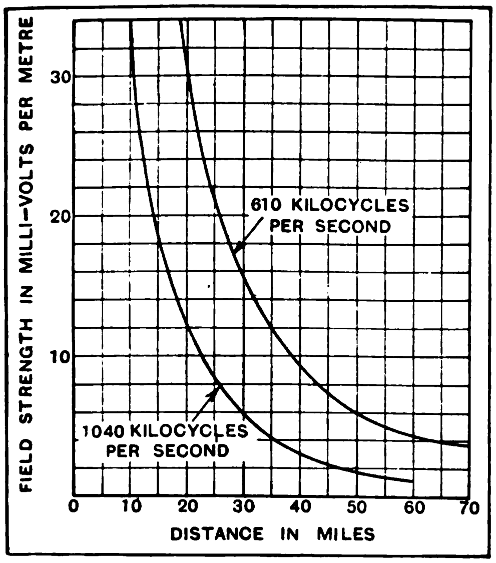


Figure 1

An examination into the significance of these proposals shows that in a way broadcasting finds itself in a more embarrassed situation than before. From having previously been comparatively free from control it has now been confined within a zone amounting in all to no more than 1,014 kilocycles, and this too without taking account of the 220 metres wavelength allotted to shipping as mentioned above, which will in practice not mean a fixed frequency but a band of considerable breadth. The frequency zones that broadcasting has been granted in addition, comprising lower wavelengths from 50 metres downwards, are at present of no very great importance for the development of normal broadcasting in Europe and in this connection are therefore disregarded.

On the other hand, the resolutions passed in Washington imply a distinct gain, in so far as we are now actually able to say what lines are to be followed. From the point of view of principle, this is more or less of secondary importance, as all countries have conformed to the regulations in question and thus one and all have to come in line with the new order. The resolutions will come into force on the 1st January 1929, except those affecting the higher wavelength zone for broadcasting, for the enforcement of which a further respite of one year has been granted.

The wavelength distribution for which the Geneva Plan has been worked out comprises only the zone from 200 to 600 metres, whereas stations working on other wavelengths have had to rely on their right of priority, which in fact has as a rule been respected. This might have been satisfactory enough at a time when there were no restrictions as to wavelength either upwards or downwards, but as soon as the Washington resolutions come into force, matters will be very different. It is obviously no longer either reasonable or fair to regard the two bands as separate, so that a few privileged countries, actually not more than seven, solely on grounds of priority, may lay claim to the higher wavelengths, while the lower band is allotted on a basis that is independent of the former and to which all are alike entitled. When the allocation is made all frequencies should be included and the question regarded as a whole.

Area and Population as Principles Governing the Distribution of Wavelengths

Before proceeding further, mention should be made of the principles laid before the Technical Committee of the Union Internationale by the author at the time—principles which, with certain modifications, formed the basis of the distribution now in force. The first of these contentions was that the number of wavelengths which a country is entitled to possess should be in a fixed proportion to the area of the country. The second proposed that consideration should be given to the size or density of the population.

As regards the first of these principles, it must still be considered to have full force. It may be assumed with approximate accuracy that a broadcasting station of a certain power and with normal equipment has the same range, regardless of the country in which it is erected—there are certainly some exceptions to this, such countries as, for instance, Norway and Switzerland, and part of Sweden, with very mountainous and wooded terrain, are at a disadvantage, whereas on the other hand, the conditions in Holland and Denmark are more favourable than the average. If we take as our basis the idea that every individual, to whatever country he belongs, shall be equally privileged as regards the possibilities of listening-in, the problem of wavelength would be solved simply enough—viz., allotted in proportion to the area of each country. For reasons which will be more closely dealt with later on, however, the time has apparently not yet arrived when we can accept this simply and solley as the basis of distribution; if we are not to lose continuity in the development, we must also give consideration to other factors.

As to the principle of population, the argument produced at the time in favour of this was that the more densely populated areas were better entitled to be supplied with more convenient means of "receiving" than sparsely populated districts, and in consequence certain countries should be allotted a greater number of wavelengths. It may be remembered in this connection that these proposals were made in 1925, that is to say, at a period when the size of the biggest commercial transmitters existing on the market was at the most 1½ kilowatts. This way of looking at the subject might have been justified at the time by the difficulty of building stations of sufficient power, but nowadays that point of view can hardly be considered tenable, seeing that transmitters of as much as 50 kilowatts and more are now standardised and may be procured at a reasonable price. In certain cases better results and increased efficiency are obtained by the removal of the station to a more suitable locality.

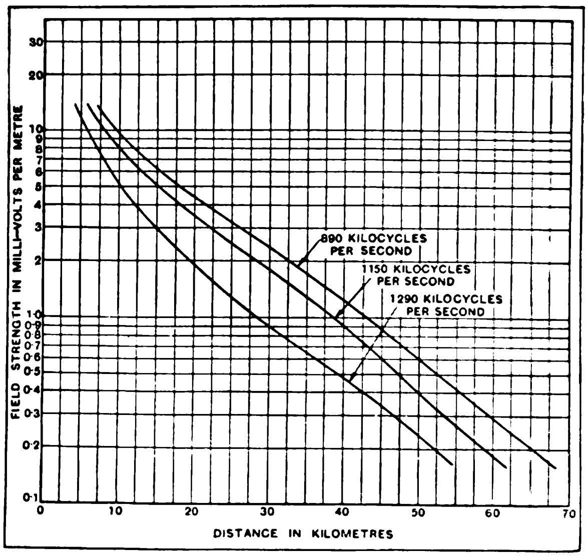


Figure 2

In this connection I venture to quote from the minutes of the meetings of the Union's Technical Committee, held at later dates, a recommendation mentioned in several places and reading as follows: "Fewer stations, greater power"—a principle which is fundamentally quite true and the truth of which, as such, is worthy of being emphasised. It goes without saying that it is in densely populated areas that an outlay of capital for higher-powered transmission will pay best, besides giving the listeners-in within the service area better possibilities of reception, and bringing to the business an increased income from new licence-holders.

Observations on the Question of Modifying the Primary Basis of Distribution

The question of wavelength distribution must not, however, be viewed merely against a theoretical background; account must also be taken of the position of the present stage of development. The author does not mean by this that the population principle should at once be entirely eliminated, as in certain countries this would involve too sudden a reversal of conditions. A gradual modification is a matter of minor importance and would not seriously inconvenience the broadcasting organisations affected, but enable them to effect the change gradually and without too much friction.

The primary principle that, according to the author's proposal, should be made the basis of a revised allocation of wavelengths is as follows:

Every country would obtain the right to a number of wavelengths as corresponding to a function of the country's area and population expressed in percentage, calculated on the basis of area plus one-half the population.

In Table I a summary has been made according to the latest available official statistics on the areas and populations of the countries of Europe, with the exception of Russia and Turkey in Europe. The total area amounts to 5,329,500 sq. kilometres and the population to 361.5 millions. In the last column have been worked out for each country comparative numbers according to the formula $a + b/2$, where a denotes the area and b the population, both expressed in percentage of the total figures.

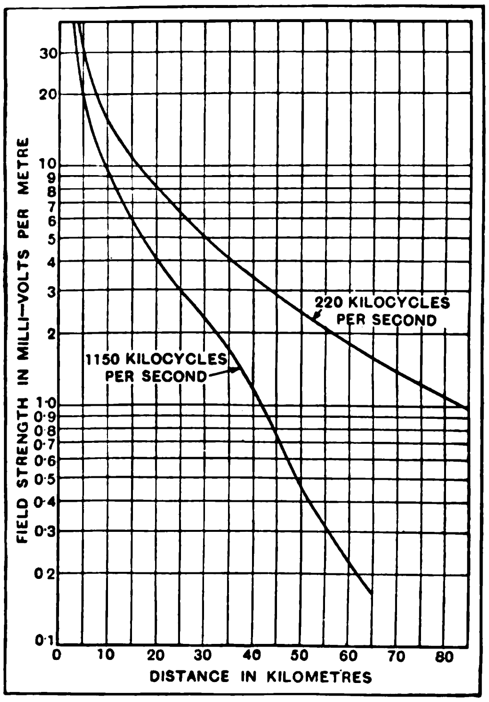


Figure 3

If we compare the comparative numbers deduced according to this formula with those obtained if the *same* value were given both to area and population, we find that only a few unimportant modifications take place slightly to the disadvantage of small and densely populated countries, while corresponding advantages accrue to states with a large area but comparatively small density of population. I would emphasise the fact that the table may obviously be adapted to admit of such modifications as may be rendered necessary by special requirements, such as, in particular, unfavourable geographical conditions, polylingual nations, etc., and that, conversely, it may be possible to make certain limitations wherever theoretical deductions have produced abnormally high comparative numbers.

TABLE I

Comparative Numbers for Wavelength Distribution in Proportion to Superficial Content Area and Population

Country	Superficial Content (a)		Population (b)		Comparative Numbers	
	100 sq. Kms.	%	Mill.	%	$a + b/2$	%
Albania......	275	0.52	0.83	0.23	0.635	0.42
Austria......	838	1.57	6.58	1.83	2.485	1.66
Belgium.....	304	0.57	7.87	2.19	1.665	1.11
Bulgaria.....	1,031	1.94	5.48	1.52	2.700	1.80
Czecho-Slovakia...	1,404	2.63	14.24	3.95	4.605	3.07
Denmark....	429	0.81	3.42	0.95	1.285	0.86
England.....	2,448	4.59	45.21	12.55	10.865	7.24
Esthonia.....	475	0.89	1.12	0.31	1.045	0.70
Finland......	3,885	7.29	3.29	0.91	7.745	5.16
France......	5,510	10.34	40.74	11.31	15.995	10.66
Germany.....	4,704	8.82	62.54	17.37	17.505	11.67
Greece.......	1,270	2.38	6.20	1.72	3.240	2.16
Holland......	408	0.77	7.52	2.09	1.815	1.21
Hungary.....	929	1.74	8.37	2.32	2.900	1.93
Iceland......	1,028	1.93	0.10	0.03	1.945	1.30
Ireland......	698	1.31	2.97	0.85	1.735	1.16
Italy........	3,097	5.81	40.55	11.26	11.440	7.63
Lettland.....	658	1.23	1.86	0.52	1.490	0.99
Lithuania....	561	1.05	2.23	0.62	1.360	0.91
Luxemburg...	26	0.05	0.27	0.07	0.085	0.06
Norway......	3,238	6.08	2.77	0.77	6.465	4.31
Poland......	3,883	7.29	29.25	8.12	11.350	7.57
Portugal.....	887	1.66	5.62	1.56	2.440	1.63
Roumania....	2,942	5.52	16.98	4.71	7.875	5.25
Spain........	4,979	9.34	21.62	6.00	12.340	8.23
Sweden......	4,485	8.42	6.07	1.69	9.265	6.18
Switzerland ..	413	0.78	3.94	1.09	1.325	0.88
Yugoslavia...	2,490	4.67	12.49	3.47	6.405	4.27

Wavelength Allocation According to the Geneva Plan

For the sake of comparison with the calculation, worked out in Table I, of the new figures proposed as a basis for a revised wavelength distribution, there is given in Table II, as a supplement to the above table, a comprehensive table of the Plan now in force. After the introduction of a third factor, borrowed from the official statistical information drawn up by the League of Nations regarding the use of the telephone and the telegraph in each country, it was resolved that a distribution should be made among the different countries in accordance with Table II:

This table relates only to the exclusive wavelengths, and Russia has here been excluded from the list, that country not having been represented at the Washington Conference and its attitude towards the question being still unknown. If we examine Table II side by side with Table I, we find agreement in the main, but in certain cases there are considerable differences. Thus, some countries have been allotted, on the Geneva Plan, the same number of wavelengths as others whose area is ten times greater. From a purely technical point of view every one must, of course, admit that the situation of the country that has received a less favourable allotment is fairly hopeless as regards the possibility of carrying on effective broadcasting and that, in such cases, justice and equity demand that a change should be made.

TABLE II

Wavelength Distribution According to the Geneva Plan

Country	No. of Exclusive Wavelengths	Country	No. of Exclusive Wavelengths
Albania......	1	Ireland......	1
Austria......	2	Italy.......	5
Belgium.....	2	Lettland....	1
Bulgaria.....	1	Lithuania ...	1
Czecho-Slovakia...	3	Luxemburg......	1
Denmark....	1	Norway.....	3
England.....	9	Poland......	4
Esthonia.....	1	Portugal....	1
Finland......	2	Roumania...	2
France......	9	Spain.......	5
Germany.....	12	Sweden.....	5
Greece.......	1	Switzerland......	1
Holland.....	2		
Hungary.....	1	Yugoslavia.....	1
Iceland......	—		

The Principles for the Mutual Location of the Wavelengths

The second question of at least equal importance to that of the allocation of the *number* of wavelengths to each country is that of the *mutual location* of stations within the 200–600 metre zone. The number of wavelengths has been based on the principle of a frequency difference between each of 10,000 cycles per sec. Proposals have been brought forward to reduce this difference in order to make room for more stations; it would seem, however, that the time for this has not yet arrived and the present basis of distribution must be maintained for some time longer.

The principles applied in placing the stations have been, in the first place, the so-called polygon procedure, consisting in two stations whose frequencies are of about the same order, being placed at the greatest possible geographical distance apart, as a rule at distances of about 1,000 to 2,000 kms. and, secondly, the acknowledgement of a certain prior right to a previously utilised wavelength. With regard to the polygon method, I shall revert thereto later on in another connection. As to the principle of priority, which should without doubt be given the same value as before, I propose to quote what I wrote on the matter in an earlier report, as follows: "It may be considered reasonable that a station that has for years past been working on one and the same wavelength should be allowed to continue to retain it wherever possible, or, if a change must be made, that this should be done only within such a zone that existing receiving sets within the normal radius of the station need not be altered."

The consequence of this has naturally been that the "better" zone between 300 to 600 metres has been the most sought after and been the first to be utilised, while frequencies below 250 metres have, to a considerable extent, been held as a kind of reserve for future requirements. It may also be regarded as a logical result that countries whose broadcasting has been organised at a later date must in that case be content to use wavelengths within a band that has not previously been occupied.

Proposal for the Introduction of So-called Wavelength Equivalents

On the other hand, in the author's opinion, an incorrect method has been employed when, in allotting wavelengths, attention has been paid exclusively to the *number* of wavelengths apart from the question of where they are to be found within the frequency zone, and no consideration has been given to the question of their different service-value. As is well known, a wavelength of 200 metres is, as regards its efficiency, not so desirable as one of 500, wherefore they cannot be compared with one another *qua* wavelengths.

A comparative valuation of different frequencies is justified for two reasons: first, the higher the frequency the greater is the attenuation of a radiated wave; and, secondly, a higher wavelength permits the use of higher masts for the same radiation resistance and consequently gives a greater number of metre-amps. for the same primary power. In consequence of the resolutions passed by the Washington Conference, and since the possibility of a choice of wavelength outside the fixed frequency bands is almost entirely eliminated, the standpoint of equal values is still less justified than before. On the other hand, since it is desirable that the basis of any allocation of wavelengths should be equally applicable to the higher and the lower wavelength zone, the question is whether an acceptable formula can be found for allotting a value to the different frequencies in relation to one another.

Here we have several points of departure to choose from. It is possible to gauge the field-strength at various distances from a given station at different frequencies and when using the same power. Such curves have been published, *inter alia*, by *P. P. Eckersley* in a recent paper read before *The Institution of Electrical Engineers*, reproduction of which illustration (Fig. 1) has been kindly allowed. Similar results have been obtained in a comparison between measurements of the field-strength from broadcasting stations in Sweden, thus Fig. 2 shows field intensity curves from one and the same station; Fig. 3 similar curves from two different stations, in both cases with approximately the same aerial output. As the measurements in the latter case were taken over land of varying character—actually more favourable to the short-wave station—no direct comparison can be made, but the example shows clearly that there is no small difference in the efficiency of the wavelengths in question.

The object of reproducing these curves is mainly to show that it is not possible by means of measuring to secure a simple and generally applicable expression for the comparative service value of the wavelengths, chiefly owing to the fact that the field intensity as a rule is dependent on the nature of the ground in each particular case. It seems to be equally improbable to be able to deduce the desired formula on a basis of purely theoretical speculation.

Disregarding therefore the investigations made by the author into the possibilities of using strictly mathematical calculations in the derivation of a suitable formula, the following proposal is submitted: *The service value of one arbitrary wavelength in relation to another within the broadcasting band is calculated as the cube root of the ratio between the inverse values of their frequencies*, this value being hereinafter called the *wavelength equivalent.*

If for this purpose we choose 300 metres, corresponding to 1,000 kc/sec., as a standard, the desired wavelength equivalent equals the cube root of the quotient between 1,000 and the respective kilocycle number and the calculations will then be easy to work out. In Table III are given the wavelength equivalents, first for the band between 160 and 224 kc/sec. for every 10th kilocycle, secondly for the upper frequency-band for every 100th kilocycle, and in Fig. 4 they are further shown graphically as a function of kc/sec.

TABLE III

Wavelength Equivalents for Different Frequencies

Frequency in Kc/sec.	Wave-length in Metres	Wave-length Equivalent	Frequency in Kc/sec.	Wave-length in Metres	Wave-length Equivalent
162	1,852	1.84	700	428.6	1.13
172	1,744	1.80	800	375.0	1.08
182	1,648	1.76	900	333.3	1.04
192	1,563	1.73	1,000	300.0	1.00
202	1,485	1.70			
212	1,415	1.68	1,100	272.7	0.97
222	1,351	1.65	1,200	250.0	0.94
			1,300	230.8	0.92
550	545.6	1.22	1,400	214.0	0.89
600	500.0	1.19	1,500	200.0	0.87

This valuation of higher or lower frequency implies that, for instance, a wavelength between 550 and 500 metres would be regarded as having about 40 percent. greater efficiency than a wavelength of about 200 metres, and further that the wavelengths within the higher band are calculated, on an average, to be 50 to 60 percent more effective than those between 300 and 550 metres.

If we compare the values of the Table with results obtained by taking measurements, we find that they are throughout a little unfavourable to short-wave stations. It is the view of the author that, to a certain extent, this must actually be the case. The main argument against the introduction of frequency equivalents is that by increasing the power of stations working on lower wavelengths it is possible to counteract the greater attenuation and to obtain an equally long range. This reasoning is correct only within certain limitations. To obtain parity in range between a wavelength of 200 and one of, say, 1,500 metres, would require a power amounting to several hundred kilowatts, with correspondingly heavier establishment and greater running costs. On the other hand, the mathematically less exact agreement and the advantage which the formula gives to the lower frequencies can be compensated without much sacrifice by a smaller increase in the power or often even merely by adopting more suitable arrangements in order to get a better efficiency.

Exclusive and Shared Wavelengths

When the above-mentioned allocation of frequencies between 200 and 600 metres was fixed at Geneva, it was decided that the number of so-called exclusive wavelengths should be 83 and the shared waves 16. It seems in this connection that the question of this distribution should also be taken up for renewed discussion.

The reason for the existence of the shared wavelengths was the need in certain countries for utilising a smaller number of transmitting stations with only a local range. This system has for the present been adopted in most countries. In view of the present establishment the shared wavelengths cannot on that account be removed at once without further notice, but there exist strong reasons for restricting the number, say, from 16 to 12, which in all probability could be done without much inconvenience.

The shared wavelengths have been allocated fairly evenly, being distributed over the entire wavelength band, starting at 588 metres, then at 500, 400, 300 metres, and so on, downwards. An alteration in this arrangement might now profitably be made. Since it was originally the intention that those stations working on shared waves were supposed only to possess a local range and consequently to be equipped with transmitters of comparatively small power—this might be put at approximately not more than 200 watts aerial energy or about 100 metre-amps.—there is no reason why one should set apart for this purpose higher wavelengths that are more serviceable for exclusive use; on the contrary, lower wavelengths are even better adapted for that purpose.

A proposal for a new allocation of the common frequencies is made in Table IV in which the scheme now in force is also given for comparison purpose. All the 12 shared wavelengths proposed are placed below 300 metres, viz., three up to each one of the frequencies 1,100, 1,200, 1,350 and 1,500 kilocycles/sec.

By the adoption of this reduction in the number and re-allocating the shared wavelengths: First, restrictions on the zone 500 to 550 kc/sec. are compensated for; the Washington Conference prohibits the use of this zone for broadcasting, certain countries, however, being at liberty, wherever possible, to allocate thereto stations of low power, provided that no interference is caused to commercial services. Moreover, the wavelengths of 500, 400 and 300 metres, which have actually proved not very good for joint use, are released as exclusive. Finally, the frequencies around 220 metres, which have at the same time been allotted to marine wireless traffic,

TABLE IV

List of the Present and a Proposal for New Shared Wavelengths

Present Wavelengths		Proposed Wavelengths	
Frequency in Kc/sec.	Wavelength in Metres	Frequency in Kc/sec.	Wavelength in Metres
510	588.2	1,090	275.2
520	577.0	1,100	272.7
530	566.0	1,110	270.3
600	500.0		
		1,190	252.1
750	400.0	1,200	250.0
1,010	297.0	1,210	247.9
1,020	294.1		
1,080	277.8	1,350	222.2
		1,360	220.6
1,090	275.2	1,370	219.0
1,100	272.7		
1,180	254.2	1,480	202.7
1,190	252.1	1,490	201.3
		1,500	200.0
1,200	250.0		
1,470	204.1		
1,480	202.7		
1,490	201.3		

might perhaps conveniently be used by stations having common wavelengths, in cases where the interference from either side may be expected to be negligible.

Application of the Principle of Wavelength Equivalents

To return to the discussion on the exclusive wavelengths, it has previously been mentioned that the total range of frequencies available for broadcasting amount in all to 1,014 kc/sec., which, allowing for a difference of 10 kilocycles between stations, corresponds to 103 usable frequencies. After deducting the proposed 12 shared wavelengths there thus remain a total of 91 for distribution amongst all the countries of Europe.

It is proposed that the distribution of these should be carried out on the following principle:

Each country to be allotted that number of frequencies of which the sum of the wavelength equivalents, expressed in percentages, corresponds to the respective comparative numbers given in Table I.

If we work out the total wavelength equivalents for all frequencies, we obtain, after deducting the shared wavelengths, the number 98.45. From this we must further deduct 1.7 for the big station in Moscow working on about 1,450 metres, which we must take into account for the purposes of this calculation. On wavelengths below 600 metres, on the other hand, there are in Russia at present only a couple of installations of minor importance. The final result will then be 96.75. If, further, we convert the absolute value of each wavelength equivalent in Fig. 4 and express it as a percentage of the total, then the sum of the percentage equivalents of the wavelengths each country is entitled to use will equal the comparative numbers calculated in Table I.

The gist of this is perhaps best explained by means of examples. In the case of most countries the new principle of distribution results in no change. For Great Britain the application of the formula would entail a certain reduction of the wavelengths now provided. Thus, England has, according to Table I, the comparative number 7.24, and with the 10 wavelengths, including Daventry, which are now in use, she would receive an absolute equivalent of 11.27, corresponding in percentage to 11.65. A strict application of the principle would therefore involve a surrender of a couple of the existing lower exclusive wavelengths. The application of the formula would likewise prove disadvantageous to Sweden and Germany, compared with the present arrangement, while on the other hand, Finland, Italy, Norway, Poland, Spain and Hungary, *inter alia*, would find their position improved. (For possible modifications when the formula is brought into effect, see under final observations.)

Group Allocation of Wavelengths instead of the Polygon Method

As regards the determination of the frequencies that the various stations must use, the author's view is, as already pointed out, that the principle of priority should still be adhered to as far as is feasible when the distribution is made; concerning the application of the polygon method however, this system might usefully be made the subject of discussion.

As is well known, the radiation from a transmitting station is of two kinds, viz., ground-radiation and space-radiation, of which the former represents the radiation of service to listeners within the normal radius, while the latter as a rule is useful for listeners at very great distances. Experience further goes to show that the space-radiation in the case of the frequencies used in broadcasting returns by reflection to the earth's surface with a maximum of strength at distances of about 1,000 to 2,000 kms., which, when the polygon method is employed, is about equivalent to the distance between two stations of closely related frequencies.

The consequence of this is—and a great many complaints from different quarters testify to the fact—that listeners not infrequently experience great difficulty in distinguishing between the programme of their own station and that of the foreign station next to it in frequency, although it may be remote in point of distance. It is not intended to try in any way to depreciate or disregard the demand for selectivity in receiving sets, but the fact remains that great inconvenience is caused by the present system. There are, for instance, continental stations which, owing to their high power and powerful ether radiation, after nightfall can be heard splendidly in neighbouring countries within the crystal-range of their own local stations, and even on crystal sets employed for the reception of local stations. Moreover, it may be supposed that these interferences will be felt in proportion as the number of higher power stations increases.

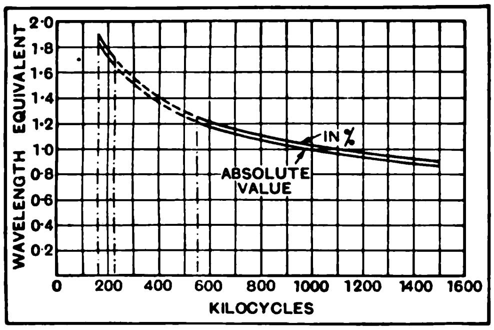


Figure 4

One way in which the author considers it possible, at least in part, to eliminate this trouble, is to substitute for the polygon method what may most suitably be termed the "group-allocation" of the wavelengths, which would mean that, *if a country possesses the right to several frequencies, these frequencies should be allotted in groups of three or four adjacent bands.*

In this there are at least two advantages to be gained: first, the broadcasting organisation in each country will itself become responsible for the frequencies within each band being kept constant, which would be quite easy when the stations are subordinate to one and the same authority—at the same time the work of the international wavelength control would be lessened—and if they fail in their efforts, their own listeners and not, as is now the case, listeners outside the country, who have nothing to do with the matter, will be the sufferers. Secondly, many of the disturbing effects of the space-radiation would be eliminated, since they would come within a considerably broader frequency-band, and thus listeners to their own local stations will not be troubled by it to such an extent as at present. And a third advantage is that owners of sufficiently selective sets will be afforded better chances of picking up and identifying stations over greater distances. Two stations adjacent in frequency already exist in England, namely, Aberdeen and Daventry Experimental (5GB). Whether or not these disturb one another in England I do not know, but that they produce interference on the Continent is an acknowledged fact.

It may be added that, as matters stand to-day, the demand for increased transmitting power is often quite as fully justified by the plea of international competition as by the desire of the station to increase its own range. The former way of viewing the matter, which, of course, does not tend to a sound development of broadcasting, would, if the group-allocation of wavelengths were introduced, have less grounds for justification.

Summary

The views submitted above regarding a revision of the system now in force for allocating the wavelengths of the European broadcasting stations may be summarised as follows:—

(1) That every country shall have the right to such number of frequencies as corresponds to a function of the country's area and population, expressed as a percentage, for which purpose the first factor is taken as the whole, and the latter as half, the numerical value.

(2) That such right shall involve the necessity, before a certain date to be fixed by the Union or other International Conference, of taking into actual use the frequencies allotted, and if this is not done, then, by agreement, such frequencies may be disposed of in some other way, until the International Radio Conference of 1932 determines otherwise.

(3) That all wavelengths that are available within the frequency-bands fixed by the Washington Conference shall be distributed on a common basis.

(4) That the valuation of different frequencies shall be made by the introduction of so-called "wavelength equivalents" on the basis of the formula here drawn up by the author, calculated, in the manner suggested, as the cube-root of the ratio between the inverse values of their frequencies.

(5) That the number of shared frequencies be reduced, to consist of 12 wavelengths instead of the present 16, such stations not being permitted to use more power than 200 watts in the aerial or about 100 metre-amps.

(6) That in the allotment of frequencies to various stations and in the application of the

principle of priority investigations be made into the possibility of introducing a certain "group-allocation" instead of the polygon method.

(7) That such deviations from the principles outlined above may be made as special circumstances require.

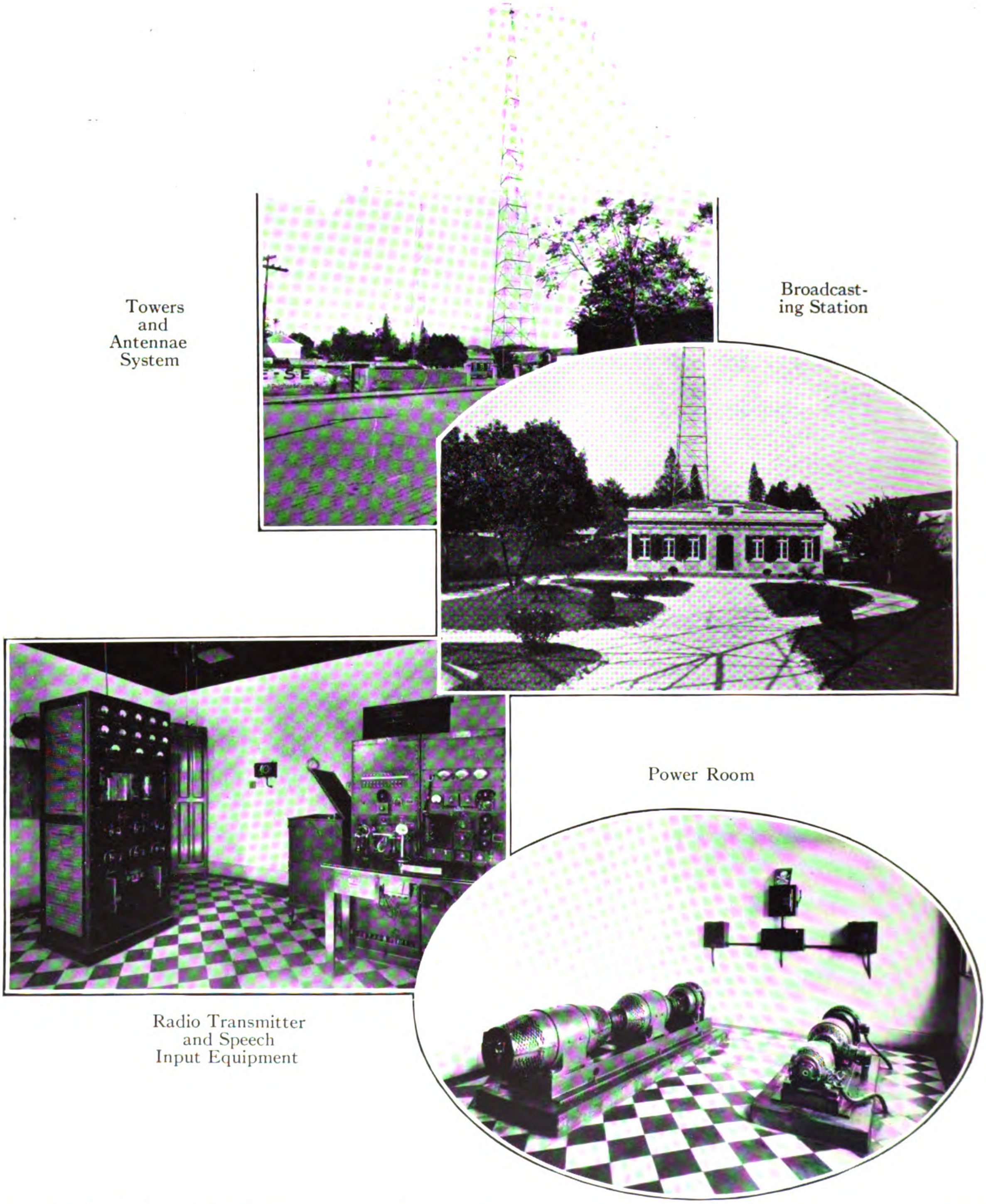
Final Observations

Before closing this article I would like to make a few final remarks and observations. First, then, it may be pointed out that the proposals and views submitted above have not been offered with the idea of procuring for my own or any other country greater advantages than those they have previously enjoyed or may be expected to enjoy in the future, but they represent an attempt to deal with relative questions from an international angle. The object, therefore, is primarily that the views here submitted shall form a basis for a comprehensive enquiry and for further discussion of these problems, and contribute towards giving permanent shape to the international system the foundations of which have been laid by the Geneva Union, and thereby conduce to the continued development of broadcasting.

It may also be emphasised that it is not, in the author's opinion, either possible or expedient to bring these proposals into immediate effect on the strict basis of his theoretical deductions, but, on the contrary, common principles of application are inevitably necessary, exceptions, however, being made in cases where they are deemed to be justified.

Broadcasting has not developed uniformly in all countries, nor, of course, is it likely to do so in the future. The suppression of what has once been created in favour of newly arisen demands cannot perhaps be avoided in a number of cases, but, on the other hand, it must be admitted that this cannot be done all in a moment; we must keep pace with the discovery of fresh means for solving the problems that arise. Nor can broadcasting afford to let employable frequencies be kept in reserve for an indefinite period; they must be utilised as and when required (point 2 in the summary). At the same time, it is the author's intention, in this article, to give a comprehensive idea of the prevailing conditions and of the difficulties with which broadcasting, regarded internationally, has at present to contend, and also that any claims that may arise must be considered by everyone in their proper light and adjusted accordingly.

Desire has in several quarters been expressed for a revision of the present system with a view to its being brought into line with the resolutions of the Washington Conference. In submitting this article, with the views on the various problems expressed therein and proposals for their solution, the author ventures to express the lively hope that, as these questions may shortly be expected to be taken up for international discussion, his recommendations may happily serve their purpose.



Towers and Antennae System

Broadcasting Station

Power Room

Radio Transmitter and Speech Input Equipment

Broadcasting Station SQIG (1 KW). It is owned and operated by Sociedade Radio Educadora Paulista, Sao Paulo, Brazil.

Sheath Losses In Single-Core Cables For Three-Phase Transmission[1]

By T. N. RILEY

European Engineering Department, International Standard Electric Corporation

IN the present state of our knowledge of cable dielectrics, mechanical considerations point to 66,000 volts as the highest transmission pressure for which a three-core cable can be constructed to operate satisfactorily. For three-phase transmission pressures above this it is necessary to use three single-core cables, and with these the circulating currents in the lead sheaths when these are bonded become of importance.

In addition to the circulating current losses there are also eddy current losses in each sheath, but these eddy current losses are always relatively small and, except when the sheaths are in contact, are negligible. The case where the sheaths are in contact, however, is that for which the total sheath losses are least, compared with the copper losses, and, therefore, the neglect of a small component of the sheath losses is of no importance in determining the carrying capacity of the line. They can therefore be neglected in practice.

While accurate mathematical analyses have been made which enable the total losses to be calculated,[2] these lead to complicated formulæ, which are inconvenient for practical use; and, on account of normal manufacturing variations, do not give more accurate practical forecasts than simpler approximate formulæ. The sheath thickness, for example, may vary from the mean value assumed, and the spacing cannot be absolutely constant under practical conditions of laying.

The following analysis leads to simple formulæ which can be easily applied, and which give results checking closely with experimental values.

Single-Phase Transmission

When two lead-sheathed cables are used for single-phase transmission, if M is the mutual inductance between the core loop and the sheath loop, and I is the current in the core, the e.m.f. induced in the sheath is $M\omega I$, where ω is $2\pi \times$ frequency.

Capdeville gives

$$M = \left[1 - \frac{2e^2}{f^2 - e^2}\log_e\frac{f}{e} + 2\log_e\frac{d}{f}\right]$$

absolute units per unit length,

where d is the distance between cable centers, and e and f are the inner and outer radii of the sheath respectively. The mathematical derivation of this formula is given in full in the original paper, and also in Messrs. Melsom and Beer's paper on "The Current Rating of Single-Conductor, Lead-Covered, Low-Tension Cables on Single-Phase Alternating-Current Circuits."[3] It is not therefore necessary to reproduce it here. As Fig. 1 shows, this formula gives a result which agrees exactly with experiment, but as the first two terms very nearly cancel each other it is a sufficiently close practical approximation to take $M = 2\log_e\frac{d}{f}$ absolute units per unit length of circuit.

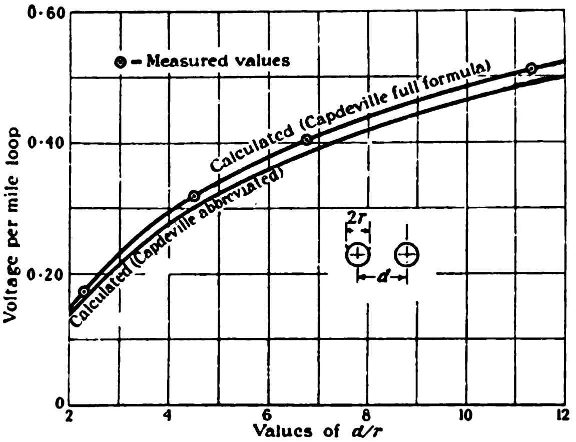


Figure 1—Sheath Voltages Induced in Two Single-core Cables per Ampere of Core Current at 50 Cycles per Sec. The values shown are mean values of tests from 10 to 300 amperes.

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[1] Reprinted, with modifications and acknowledgements, from the *Journal of the Institution of Electrical Engineers*, Vol. 65, No. 371, November 1927.

[2] Dwight, *Electric Journal*, 1924, Vol. 21, p. 62. Carter, *Camb. Phil. Mag.*, Vol. XXIV, Part 1, p. 65, 1928.

[3] *Journal I. E. E.*, 1295, Vol. 63, p. 199.

Reduced to practical units this becomes

$$M = \frac{1.48}{10^3} \log_{10} \frac{d}{r} \text{ henrys per loop mile}$$

where r is used instead of f for the sheath outer radius.

In making calculations in the three-phase case, therefore, the abbreviated form of Capdeville's formula has been taken for simplicity, though the general formulæ developed are correct for any value of the mutual inductance.

Three-Phase Transmission

A three-phase transmission line consisting of horizontally spaced single-core cables can be considered as split up into three sections as indicated in Fig. 2, each of which forms a single loop having conductors of the same dimensions as the original cables.

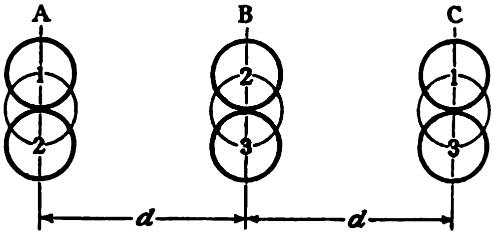

Figure 2—Three-phase Line Split into Three Single-phase Sections.

The currents in the original phases A, B and C can be considered as being made up of the following currents in the separate loops:

$$i_1 = i \sin \theta$$

$$i_2 = i \sin\left(\theta + \frac{2\pi}{3}\right)$$

$$i_3 = i \sin\left(\theta - \frac{2\pi}{3}\right)$$

The original current in phase A is then

$$i_A = i_1 - i_2 = \sqrt{3}i \sin\left(\theta - \frac{\pi}{6}\right)$$

in phase B

$$i_B = i_2 - i_3 = \sqrt{3}i \sin\left(\theta + \frac{\pi}{2}\right)$$

and in phase C

$$i_C = i_3 - i_1 = \sqrt{3}i \sin\left(\theta + \frac{7\pi}{6}\right)$$

The phase relationships of these currents are shown in Fig. 3.

Let

M_1 = mutual inductance between core 1 and sheath 1.

M_2 = mutual inductance between core 2 and sheath 2.

M_3 = mutual inductance between core 3 and sheath 3.

For the usual symmetrical spacing as shown in Fig. 2, $M_3 = M_2$, and, for simplicity, this case only is considered below, though the principle of the calculation can be applied also to unequal spacings.

When the dimensions are small compared with the spacings, as is usually the case in practice for flat spacings, it is clear from symmetry that sheath 2 will be linked with exactly half the magnetic flux which links sheath 1 due to a current in core 1. The mutual inductance of sheath 2 with core 1 will, therefore, be half the mutual inductance of sheath 1 with core 1, i.e., it will be $\frac{1}{2}M_1$. Similarly, since there can only be one value of the mutual inductance between two circuits, $\frac{1}{2}M_1$ is also a measure of the flux produced by unit current in sheath 2 which is linked with core 1. What we need, however, is a measure of the flux produced by unit current in core 2 which is linked with sheath 1. Now unit currents in core 2 or sheath 2 will produce the same field external to the sheath, but unit current in the core produces an additional flux between core and sheath. This flux, however, is not linked with sheath 1 either, so that the mutual inductance between core 2 and sheath 1

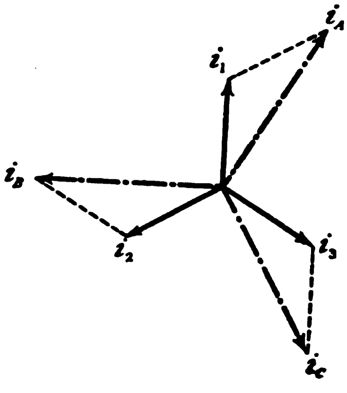

Figure 3—Vector Diagram Showing Phase Relationship of Currents in Three-phase Line and Single-phase Sections.

is also $\frac{1}{2}M_1$. But the total flux produced by unit current in core 2 which is linked with sheath 2 is proportional to M_2, and if this flux is not also to link sheath 1 it must return inside sheath 3, so that the difference of the quantities M_2 and $\frac{1}{2}M_1$ is a measure of the flux due to unit current in core 2 which links sheath 3, i.e., $M_2 - \frac{1}{2}M_1$ is the mutual inductance between core 2 and sheath 3. It is similarly the mutual inductance between core 3 and sheath 2.

This can easily be demonstrated by circulating an alternating current in cores A and B only and measuring the induced e.m.f.'s at the near end of each of the loops formed by the three lead sheaths when bonded at the far end. That between the sheaths of A and B will be proportional to M_2, that between A and C will be proportional to $\frac{1}{2}M_1$, and that between B and C will be proportional to $M_2 - \frac{1}{2}M_1$.

Consider first the e.m.f.'s induced in sheath 1 by the currents in the cores.

The e.m.f. induced in sheath 1 due to current in core 1

$$= M_1\omega i_1.$$

The e.m.f. induced in sheath 1 due to current in core 2

$$= -\tfrac{1}{2}M_1\omega i_2.$$

The e.m.f. induced in sheath 1 due to current in core 3

$$= -\tfrac{1}{2}M_1\omega i_3.$$

The total e.m.f. in the loop formed by the sheaths of circuit 1 is the sum of the above

$$= M_1\omega i_1 - \tfrac{1}{2}M_1\omega i_2 - \tfrac{1}{2}M_1\omega i_3.$$

Substituting the values of i_1, i_2 and i_3 we have

$$e_{S1} = M_1\omega i \sin\theta - \frac{M_1}{2}\omega i \sin\left(\theta + \frac{2\pi}{3}\right) - \frac{M_1}{2}\omega i \sin\left(\theta - \frac{2\pi}{3}\right) = \frac{3}{2}M_1\omega i \sin\theta. \quad (1)$$

Similarly we have for the loop formed by the sheaths of circuit 2,

$$e_{S2} = M_2\omega i_2 - \left(M_2 - \frac{M_1}{2}\right)\omega i_3 - \frac{M_1}{2}\omega i_1,$$

which on substitution reduces to

$$e_{S2} = \sqrt{3}\,\omega i\left\{\left(M_2 - \frac{M_1}{4}\right)\cos\theta - \frac{\sqrt{3}}{4}M_1 \sin\theta\right\}, \quad (2)$$

and for the loop formed by the sheaths of circuit 3,

$$e_{S3} = \sqrt{3}\,\omega i\left\{-\left(M_2 - \frac{M_1}{4}\right)\cos\theta - \frac{\sqrt{3}}{4}M_1 \sin\theta\right\}. \quad (3)$$

Reverting now to the actual condition of three single sheaths, let us consider the currents set up in the sheaths by these e.m.f.'s. Fig. 4 shows diagrammatically the relationship of the circulating currents and induced e.m.f.'s, the cores being separated into three planes for clearness. The end bonds ABC and A'B'C' are supposed to have no resistance.

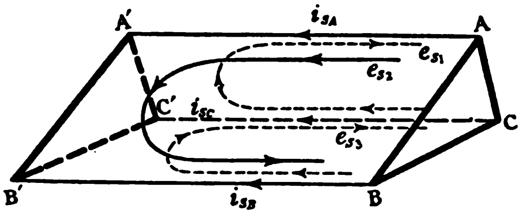

Figure 4—Diagram Illustrating Circulating Currents and e.m.f.'s in Sheaths of Three Single-core Cables.

The inductances of the sheaths on unarmoured cables are usually negligibly small compared with the resistances, and the impedances of the sheaths are approximately equal. Suppose, however, in the first instance, that they are not equal and that

Z_O = impedance of each outer
Z_M = impedance of center sheath.

Then for the loop CC'A'A (loop 1)

$$e_{S1} = i_{SC}Z_O - i_{SA}Z_O,$$

for the loop AA'B'B (loop 2)

$$e_{S2} = i_{SA}Z_O - i_{SB}Z_M,$$

and for the loop BB'C'C (loop 3)

$$e_{S3} = i_{SB}Z_M - i_{SC}Z_O,$$

also

$$i_{SA} + i_{SB} + i_{SC} = 0.$$

From these equations it follows that

$$i_{SA} = \frac{e_{S2}Z_O - e_{S1}Z_M}{Z_O(Z_O + 2Z_M)},$$

$$i_{SB} = \frac{e_{S3} - e_{S2}}{Z_O + 2Z_M},$$

$$i_{SC} = \frac{e_{S1}Z_M - e_{S3}Z_O}{Z_O(Z_O + 2Z_M)}.$$

Inserting the values of the sheath e.m.f.'s [equations (1), (2) and (3)] we have

$$i_{SA} = \frac{\sqrt{3}\omega i}{2Z_M}\left\{\left(M_2 - \frac{M_1}{4}\right)\left(\frac{2Z_M}{Z_O + 2Z_M}\right)\cos\theta - \frac{\sqrt{3}M_1}{2}\cdot\frac{Z_M}{Z_O}\sin\theta\right\},$$

$$i_{SB} = -\frac{\sqrt{3}\omega i}{2Z_M}\left\{\left(2M_2 - \frac{M_1}{2}\right)\left(\frac{2Z_M}{Z_O + 2Z_M}\right)\cos\theta\right\},$$

$$i_{SC} = \frac{\sqrt{3}\omega i}{2Z_M}\left\{\left(M_2 - \frac{M_1}{4}\right)\left(\frac{2Z_M}{Z_O + 2Z_M}\right)\cos\theta + \frac{\sqrt{3}M_1}{2}\cdot\frac{Z_M}{Z_O}\sin\theta\right\}.$$

If $Z_O = Z_M = Z$ the formulæ become

$$i_{SA} = \frac{\sqrt{3}\omega i}{3Z}\left\{\left(M_2 - \frac{M_1}{4}\right)\cos\theta - \frac{3\sqrt{3}M_1}{4}\sin\theta\right\}. \tag{4}$$

$$i_{SB} = -\frac{\sqrt{3}\omega i}{3Z}\left\{\left(2M_2 - \frac{M_1}{2}\right)\cos\theta\right\}. \tag{5}$$

$$i_{SC} = \frac{\sqrt{3}\omega i}{3Z}\left\{\left(M_2 - \frac{M_1}{4}\right)\cos\theta + \frac{3\sqrt{3}}{4}M_1\sin\theta\right\}. \tag{6}$$

Since Z_O is greater than Z_M it is clear that the effect of greater impedance in the outers is to cause a slight reduction of the total loss which will be more marked on the outers than in the center sheath since the second term is the preponderating one in the expressions for the currents in the outers.

In the single-phase case with the same spacing as that between outer and middle, and a current $\sqrt{3}i$ in the cores, i.e., the actual three-phase current, the sheath current will be

$$i_3 = \frac{\sqrt{3}\omega i}{2Z}M\sin\theta.$$

For purposes of direct comparison it is convenient to write the actual sheath currents in the same form with the denominator $2Z$ instead of $3Z$. The equations then become:

$$i_{SA} = \frac{\sqrt{3}\omega i}{2Z}\left\{\left(\frac{2M_2}{3} - \frac{M_1}{6}\right)\cos\theta - \frac{\sqrt{3}}{2}M_1\sin\theta\right\}, \tag{7}$$

$$i_{SB} = -\frac{\sqrt{3}\omega i}{2Z}\left\{\left(\frac{4M_2}{3} - \frac{M_1}{3}\right)\cos\theta\right\}, \tag{8}$$

$$i_{SC} = \frac{\sqrt{3}\omega i}{2Z}\left\{\left(\frac{2M_2}{3} - \frac{M_1}{6}\right)\cos\theta + \frac{\sqrt{3}}{2}M_1\sin\theta\right\}. \tag{9}$$

The maximum value of currents i_{SA} and i_{SC} is

$$\frac{\sqrt{3}\omega i}{2Z}\sqrt{\left[\left(\frac{2M_2}{3} - \frac{M_1}{6}\right)^2 + \frac{3}{4}M_1^2\right]}.$$

The sheath losses are proportional to the squares of the current values, and in the form to which the latter have been reduced a direct comparison with the single-phase case can be made by comparing the squares of the mutual inductance coefficients. In this way an equivalent single spacing can be estimated from which the losses can be easily calculated (see Table 1).

TABLE 1

1	2	3	4	5	6	7	8	9
$\frac{d}{r}$	$\log_{10}\frac{d}{r}$	$\log_{10}\frac{2d}{r}$	M_2	M_1	$\sqrt{\left[\left(\frac{2M_2}{3} - \frac{M_1}{6}\right)^2 + \frac{3}{4}M_1^2\right]}$	$\left(\frac{4M_2}{3} - \frac{M_1}{3}\right)$	Equivalent M	Equivalent Delta Spacing
			mH	mH	mH	mH	mH	
2	0.301	0.602	0.466	0.892	0.798	0.2968	0.664	1.41 d
3	0.477	0.778	0.706	1.154	1.038	0.556	0.906	1.36 d
4	0.602	0.903	0.892	1.336	1.216	0.744	1.08	1.34 d
6	0.778	1.079	1.154	1.596	1.474	1.004	1.336	1.325d
8	0.903	1.204	1.336	1.784	1.656	1.184	1.516	1.315d
12	1.079	1.38	1.596	2.04	1.914	1.444	1.770	1.305d
16	1.204	1.506	1.784	2.22	2.096	1.64	1.956	1.3 d

For practical purposes it is sufficiently accurate to take the mutual inductance between core and sheath of a single loop of unarmoured cable as

$$M = \frac{1.48}{10^3}\log_{10}\frac{d}{r}\text{ henrys per mile loop,}$$

where d is the distance between core centers and r is the sheath radius.

The loss in the case of delta spacing at distance d (see below) is proportional to the square of col. 4. For flat spacing the loss in each outer is proportional to the square of col. 6, and that in the middle sheath is proportional to the square of col. 7. The total loss is proportional to the square of the value of M given in col. 8, which is the square root of one-third of the sum of twice the square of col. 6 plus the square of col. 7. Col. 9 is the delta spacing which would give the value of M in col. 8.

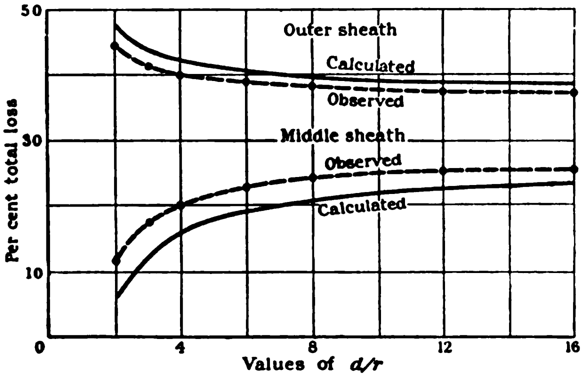

Figure 5—Calculated and Observed Proportions of Total Sheath Losses Occurring in Each Sheath of Three Single-core Cables with Flat Spacing.

The value of $d/r = 2$ corresponds to the sheaths touching, which is closer than would normally occur in practice. On the other side the spacing will rarely be so great that d/r exceeds 12, and for most cases it will give a sufficiently close approximation if an equivalent value of d of 1.33 times the distance between adjacent cores is taken. The total loss for flat spacing will then be three times the single-phase loss per sheath calculated with this spacing and the normal line current.

The total losses are divided between the three cores as follows:

TABLE 2

$\frac{d}{r}$	Outer Sheaths, Each, Per Cent	Centre Sheath, Per Cent
2	46.7	6.6
3	43.7	12.6
4	42.0	16.0
6	40.6	18.8
8	39.8	20.4
12	39.0	22.0
16	38.2	23.6

These values are plotted in Fig. 5.

Delta Spacing

It is of interest to note that the special case of delta spacing with three equidistant cores can be obtained directly from the above by writing

$$M_1 = M_2 = M.$$

We then have for the value of the e.m.f.'s in the sheaths:

$$e_{S1} = \frac{3}{2} M\omega i \sin \theta,$$

$$e_{S2} = \frac{3}{2} M\omega i \sin \left(\theta + \frac{2\pi}{3} \right),$$

$$e_{S3} = \frac{3}{2} M\omega i \sin \left(\theta - \frac{2\pi}{3} \right).$$

It is clear by inspection that the induced e.m.f.'s in the loop are $\frac{1}{2}\sqrt{3}$ times those which would be obtained on the single-phase loop formed by taking any two of the cores. This corresponds to the same induced voltage per single sheath as in the single-phase case, since the circulating currents in the three sheaths will differ in phase by 120°.

This may be illustrated from two of the tests given in Dunsheath's paper.[4] Mr. Dunsheath has been good enough to furnish the author with his cable dimensions and test-results. The manner in which values calculated as above compare with measured ones is shown in Tables 3 and 4.

TABLE 3

Dunsheath's Fig. 5. Current 160 amps.
Voltage per Single Sheath on Separate Single-Core Cables

Spacing	1 in.	2 in.	3 in.	4 in.	5 in.	6 in.
Calculated value	1.01	1.27	1.48	1.64	1.78	1.905
Test-result	1.006	1.243	1.423	1.563	1.635	1.963

TABLE 4

Dunsheath's Fig. 8. "S. L." Cable
Near End Open-Circuit Voltage with Far End Bonded

Current, in amps	100	150	208	255	300
Test value	0.75	1.05	1.1	1.55	1.95
Calculated value (full Capdeville formula)	0.593	0.89	1.24	1.51	1.79
Calculated value (approximate formula)	0.545	0.82	1.135	1.39	1.64

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[4] *Jour. Inst. E. E.*, 1927, Vol. 65, p. 476.

These figures are better compared in Fig. 6, where they are plotted.

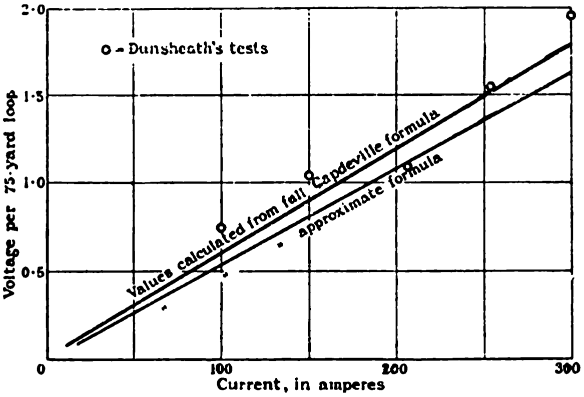

Figure 6—Comparison of Calculated Values of Sheath Loss with Those Quoted by Mr. Dunsheath in Fig. 8 of His Paper.

Returning now to the calculation of the current, we have, by substituting $M_1 = M_2 = M$ in equations (7), (8) and (9),

$$i_{SA} = \frac{\sqrt{3}M\omega i}{2Z}\sin\left(\theta + \frac{5\pi}{6}\right),$$

$$i_{SB} = \frac{\sqrt{3}M\omega i}{2Z}\sin\left(\theta - \frac{\pi}{2}\right),$$

$$i_{SC} = \frac{\sqrt{3}M\omega i}{2Z}\sin\left(\theta + \frac{\pi}{6}\right),$$

the maximum value in each case being the same as would be obtained in the single-phase case.

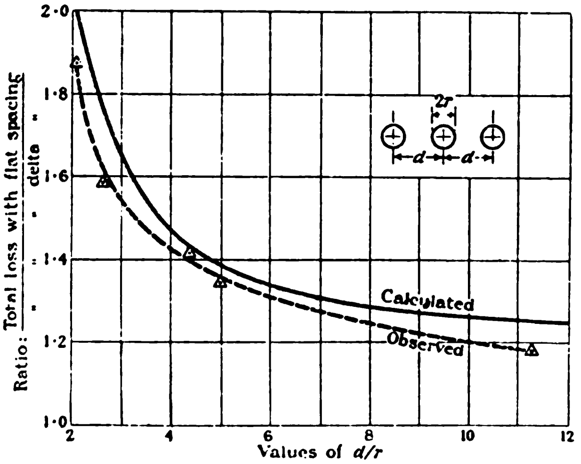

Figure 7—Ratio of Total Sheath Loss in Three Single-core Cables with Flat Spacing to Sheath Loss with Delta Spacing.

Experiments have been carried out to check these results, and the comparative measured and calculated results are shown in Figs. 7 and 8. The calculations in this case are based on the theoretical values determined as in Table 1.

Fig. 7 shows the ratio of the total sheath losses in the three cores to the loss which would occur if the three cables were equally spaced at the distance between two adjacent cables.

Fig. 8 shows the ratio of the sheath losses in each outer cable and in the middle cable to the loss which would occur in each of three cables equally spaced at the distance between two adjacent cables. It will be noted that the total loss is in general slightly less than that calculated and that the center core loss is rather higher and the outer core losses rather less than the calculated values. This is to be expected, since the inductance of the sheath circuit has been ignored in determining the actual circulating currents, and this would slightly reduce the current and therefore the total loss. It would have a more marked effect on the outers than on the middle core. For two adjacent cables the reactance was of the order of one-sixth the ohmic resistance, but for the two outers at the smallest spacing it was of the order of one-third the total resistance, and its effect begins to be appreciable. It would tend to reduce the proportion of the loss in the outer cores and to increase the proportion of the loss in the middle core. Over the practical range the loss in the outers is from 1.5 to 2.5 times that in the middle core.

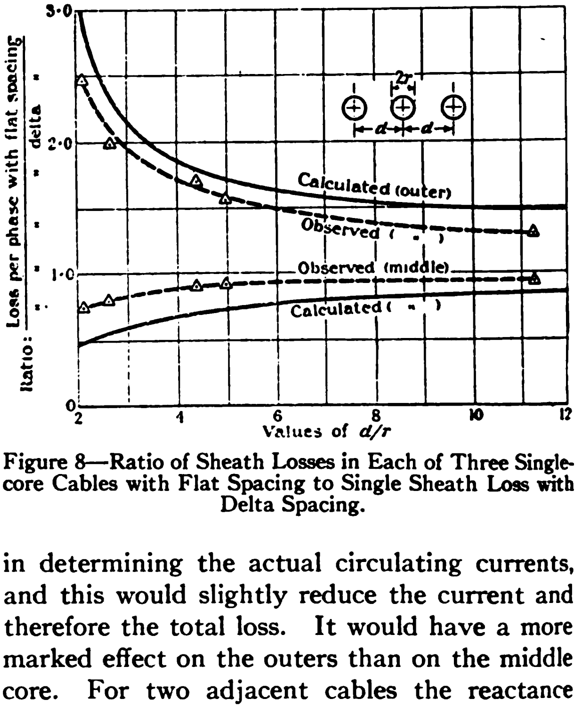

Figure 8—Ratio of Sheath Losses in Each of Three Single-core Cables with Flat Spacing to Single Sheath Loss with Delta Spacing.

In order to show how closely the measured values compare with those calculated on the assumption of an equivalent spacing of 1.33*d*, the values shown in Table 5 have been calculated.

It will be noted that, considering the short length on which tests were made and the consequent difficulty in eliminating end-effects, the agreement is exceptionally good, and the method of calculation is sufficiently accurate to involve no appreciable error in estimated loadings.

In order to make the method perfectly clear the full calculation is given below for one position of the cables tested. These were three 25-yard lengths of 0.25 sq. in. single-core cables with a sheath 1.55 in. inside and 1.75 in. outside diameter. The sheath resistance per 25-yard length was 0.0129 ohm, the core resistance 0.00255 ohm and the core current 100 amps. Frequency = 50 periods. Distance between centers 3.82 in., so that $d/r = 4.36$.

TABLE 5

Sheath Circuit Loss per 100 Amps. Core Current
Three-Phase Flat Spacing. 25 Yards Length

$\frac{d}{r}$	Single-phase		Three-phase						
	One Leg of Circuit		Each Outer		Middle		Total Loss		Copper Loss
	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Total
2.11	1.085	0.885	2.65	2.35	0.81	0.39	6.10	5.1	76.5
2.67	1.55	1.53	3.1	3.31	1.22	0.83	7.4	7.45	76.5
4.36	3.63	3.48	6.1	6.15	3.1	2.40	15.3	14.7	76.5
4.91	4.25	4.0	6.7	6.99	3.7	2.92	17.1	16.9	76.5
11.2	8.8	9.35	11.6	13.7	7.85	7.6	31.0	35.0	76.5

For the single-phase case we have

$$M = \frac{1.48}{10^3}\log_{10}\frac{d}{r} = \frac{1.48}{10^3}\log_{10}\frac{3.82}{0.875}$$

$$= \frac{0.948}{10^3}\text{ henry per mile loop,}$$

or 1.35×10^{-5} henry per 25-yard loop.
Induced voltage in sheath

$$= M\omega I = 1.35 \times 10^{-5} \times 314 \times 100$$
$$= 0.425 \text{ volt (loop).}$$

$$\text{Current} = \frac{0.425}{2 \times 0.0129} = 16.4 \text{ amps.}$$

$$\text{Watts lost per single sheath} = (16.4)^2 \times 0.0129$$
$$= 3.48 \text{ watts.}$$

For the three-phase case we have:

$$\text{Equivalent } M = \frac{1.48}{10^3}\log_{10}\frac{1.33d}{r}$$

$$= \frac{1.13}{10^3}\text{ henry per mile loop,}$$

or 1.6×10^{-5} henry per 25-yard loop.
Equivalent induced voltage in sheath

$$= M\omega I = 1.6 \times 10^{-5} \times 314 \times 100$$
$$= 0.503 \text{ volt (loop).}$$

$$\text{Equivalent current} = \frac{0.503}{2 \times 0.0129} = 19.5 \text{ amps.}$$

$$\text{Total loss} = 3 \times (19.5)^2 \times 0.0129 = 14.7 \text{ watts.}$$

Of this total we can determine from the calculated curves in Fig. 5 what proportion of losses occur in each phase. This gives us approximately 6.15 watts in each outer and 2.4 watts in the center sheath. The actual distribution of the losses is a little less in the outers and rather more in the center. Taking, however, the calculated value, we have a sheath loss in each outer of 24 per cent of the copper loss, which, allowing for the fact that the heat has not to pass through the dielectric, would reduce the current-carrying capacity about 10 per cent. Comparing the current loading of the three spaced cables with that of a three-core cable, however, the heating due to the sheath losses is more than compensated for by the extra cooling effect due to wider spacing, and up to the limit of practical spacings the single-core cables run cooler. Dunsheath[5] shows in his Figs. 15 and 18 that 0.2 sq. in. single-core cables at 6 in. spacing run cooler than at 2.1 in. spacing, and the latter slightly cooler than a three-core cable. For 0.5 sq. in. low-tension cables Melsom and Beer[6] show a slight increase in permissible loading as the cables are separated, followed by a drop again owing to increased loss when d/r is greater than 15. The maximum current-carrying capacity in this case was reached for $d/r = 6$.

The experimental work the results of which are quoted in the paper has been carried out in the research laboratories of Messrs. Standard Telephones and Cables, Ltd.

[5, 6] *Loc. cit.*

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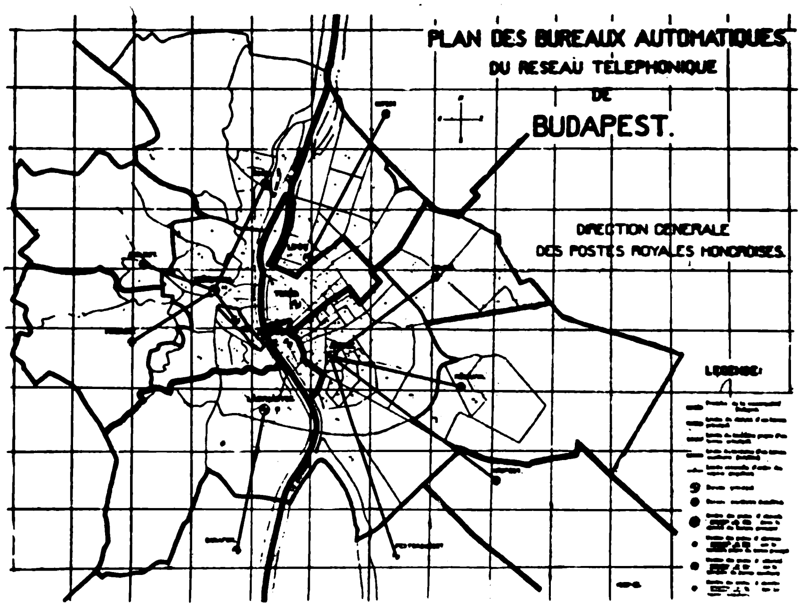


Budapest Exchange Area

Panorama of Budapest

Budapest Telephone Area

Development and Transition from Manual to Automatic

By JENÖ RÉDL
Technical Chief-Director, Hungarian Post Office

THE Hungarian Post Office has ever been on the alert to take advantage of the world's progress, and its present Administration has ever been quick to adopt improvements in its service. Thus special attention has been given to the telephone system of Hungary. It is the object of this article to present an account of the development of the Budapest area, with particular reference to the transition from manual to automatic operation.

Before proceeding further, however, it is appropriate to place on record the part played by Mr. Kolossváry, Secretary of State, who for the last forty years has been the head of the Technical Department of the Hungarian Telegraph and Telephone Administration, for he has done much to encourage advance. Moreover, it may here be recalled that in 1904, at the regular meeting of the International Telegraph Congress, which that year was held in London, the Hungarian and French delegates suggested that it would be useful also to have International meetings, at which technical problems could be decided. Accordingly, in 1908, the Hungarian Administration issued invitations to a meeting to be held in September of that year at Budapest.

Budapest was amongst the first towns in Europe to make commercial use of the telephone, the first Hungarian exchange being cut-over there on May 1st, 1881, only five years after the historic exhibition of Graham Bell's invention in Philadelphia, at the World Exhibition of 1876.

At the time of the opening of the Budapest exchange there were only three other exchanges in Europe, i.e., Friederichsberg in Germany, opened November 12th, 1877; Paris, opened June 26th, 1879; and London, opened October, 1879. The concession for the first Paris exchange—Avenue de l'Opéra—was awarded to a Hungarian, Francis Puskás, who had associations with Graham Bell and Edison. Francis Puskás was responsible for the first exchange in Budapest.

Budapest so soon developed its modest initial equipment that when the State bought it in 1897, it had 4,000 subscribers connected, whilst 500 more were eagerly awaiting service.

In the early stages of its telephone history, the Budapest area consisted of numerous small exchanges, but with the advent of the multiple switchboard these were centralized, Budapest being among the first of the European towns to take advantage of the new multiple system.

When the State took over the equipment, the original network of steel wire single conductors with earth return was speedily replaced by bronze wire metallic circuits and paper insulated lead-covered underground cables in concrete ducts. At the end of the year 1903, Budapest was furnished with its first exchange of the common battery type; it was of Western Electric development and manufacture. (The International Western Electric Company was the predecessor of the International Standard Electric Corporation.) This exchange, Teréz, had a capacity of 10,000 lines, and was accommodated in a specially designed building. By the spring of 1904 all the subscribers in Budapest, numbering about 6,900, were connected with this new central exchange, the telephone system thus functioning as a single office area. At the close of 1904 the new toll exchange was installed in the same building. As the number of subscribers increased, it became necessary to extend the Teréz exchange until 16,000 lines were connected, and as still further connections were required, a second exchange was introduced into the area. This exchange, which was named József, was also of Western Electric (now International Standard Electric) design, and was completed just before the Great War. It had a capacity of 15,000 lines, and, being furnished with modern equipment to satisfy the most exacting requirements, it attracted the attention of experts from abroad, who expressed their admiration of the performance. War-time conditions, however, made it impossible to take immediate advantage of this equipment, and it was brought into service gradually, the capacity not being reached until 1919.

In 1919 the toll exchange, which had been considerably extended, was transferred to the József building. In 1921, the capacity of the two exchanges, Teréz and József, had been practically exhausted and a relief exchange of 4,000 lines was ordered; this exchange was later extended to 6,000 lines. For nearly ten years following 1914, however, the telephone system in Budapest suffered from the unfavourable conditions of insufficient maintenance and lack of development. Not only was the introduction of a third exchange postponed, but the existing exchanges, particularly Teréz exchange, part of which is twenty-five years old, deteriorated more rapidly, owing to the abnormal conditions, so that the service was inevitably impaired.

During this period of plant retrogression, great advances had been made in the telephone art, so that when the time arrived to rebuild the telephone system, the old plans had to be entirely revised. In making their plans for ten years following 1921, the Postal Administration naturally included the provision for a modern telephone area for Budapest, and decided that the most up-to-date automatic system should be installed. The ultimate aim of establishing a full automatic system could be realized only by degrees. A change-over from the flat rate to a message rate tariff was necessary, because it was important to calculate the switch quantities for the new automatic exchange to correspond with the reduced traffic which would result from message rate service. The first step, therefore, in the investment, was the installation of service meters. This innovation was preceded by an important reform of the manual service, i.e., the substitution of the trunk indicator system for the former order wire system; and was required as a preliminary to changing over to the message rate tariff in order to eliminate the possibility of wrong connections being metered against the subscriber. These changes resulted in an improved service, since there was naturally a decrease in the average number of calls per day, and consequently a decrease in the operators' load. Actually the load was relieved to the extent of nearly 40%, so that it became possible to provide a quicker and better service, while complaints of wrong connections were almost eliminated. To draw up correctly the ten years' development scheme for the Budapest area, it was necessary to forecast the probable growth. Consequently, studies were carried out in 1920 and 1921, with the object of determining what degree of development might be expected by the end of 1930.

Population

According to official records, the population of Budapest showed in the last decades an increase as indicated in Table No. 1.

The new telephone network is, however, intended to include not only Budapest, but also the surrounding boroughs, even before these are definitely united with the Capital from an administrative point of view. Therefore, it was essential also to investigate the probable increase in population in these communities. The respective data are shown in Table No. 2. In these tables only the most important places are included; some boroughs closely connected with Budapest are not mentioned. If these are included, there were living in 1910 in the neighbourhood of the Capital 239,562 persons. It has been estimated from the above data and other facts that Budapest's population in 1930 will be approximately one million. This cannot be regarded as an overestimate, as at the end of 1926 a rough census disclosed that the population of Budapest, excluding the Army and the Police within its boundaries, amounted to 970,000. If, for the neighbouring boroughs only a small increase in population is assumed, say to 300,000 by 1930, then for the purposes of the telephone development scheme, the total population of the area in question may be estimated to be 1,300,000.

TABLE No. 1

Year	Population	Increase of the population in comparison to the previous counting		Annual Increase	
		Number of inhabitants	%	Number of inhabitants	%
1869	280,349	......	....	......	..
1880	370,767	90,418	32.2	8,220	2.9 11 years
1890	506,384	135,617	36.6	13,562	3.7 10 years
1900	733,358	226,974	44.8	22,697	4.5 10 years
1906	791,748	58,390	7.9	10,469	1.6 5 years
1910	880,371	88,623	11.2	17,724	2.2 10 years
1920	930,247	49,876	5.6	4,988	

Increase in Population of Budapest, 1869-1920

Telephone Subscribers

The gradual increase in the number of Budapest telephone subscribers can be seen from Table No. 3, and Figure 1. On the basis of these data and certain important circumstances, the increase in the proportion of the number of subscribers to the number of inhabitants was calculated year by year, and the result for 1930 was found to be 4 subscribers per 100 of population. This computation, notwithstanding various difficulties, was confirmed by recent experience, the proportion attaining 3.5% per 100 in 1925 and 3.7% in August, 1927. Thus the assumption of the proportion reaching 4% in 1930 is well founded.

In the light of the present facts, it can be stated that in 1930, Budapest's 1,300,000 inhabitants will have 52,350 main stations with 4 subscribers to every 100 of the population while the proportion, taking into account the extensions, will be 6 to 100. These results are confirmed by other more detailed studies.

Location of Exchanges

Further investigations involving consideration of the existing cable network as well as the density of telephone traffic were carried out to determine the best sites for the exchanges. Thus

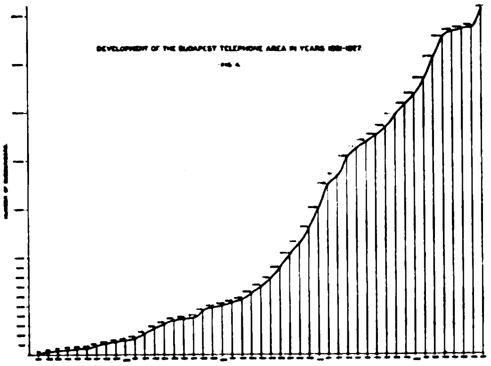


Figure 1—Development Budapest Telephone Area, 1881-1926.

TABLE No. 2

Place	Number of Inhabitants			
	1890	1900	1910	1920
Rákospalota........	6,264	11,742	25,135	35,586
Pestujhely..........	.....	......	5,545	7,860
Ujpest.............	23,521	41,836	55,174	55,825
Rákosszentmihály...	979	3,105	6,550	9,459
Czinkota...........	1,876	3,134	7,616	12,141
Pestszentlörino......	390	5,952	7,812	11,552
Kispest............	4,523	19,777	30,154	50,244
Erzsébetfalva.......	4,754	15,717	30,959	40,325
Csepel.............	2,246	4,563	9,454	13,522
Budafok............	5,243	7,267	10,943	13,470
Albertfalva.........	592	791	1,118	1,210
Budakeszi..........	3,635	4,211	5,228	5,153
Nagykovácsi........	1,803	2,012	2,226	2,238
Békásmegyer........	1,340	2,027	3,535	4,369
Budaörs............	5,281	6,100	7,383	8,033
Pesthidegkut........	1,393	1,559	2,126	3,292
Total...........	63,840	129,793	210,958	274,279
Increase	Number of Inhabitants	65,953	81,165	63,321
	%	103.3	62.5	30

Increase in Population of Boroughs Surrounding Budapest, 1890-1920.

it was possible to ascertain that, besides the existing Teréz and József exchanges, the telephone area shows obvious points of density in the inner town at Köbánya, along the Krisztina Boulevard on Mount Sváb, in the Hüvösvölgy and the Lágymányos, and that these spots must be chosen for exchanges. This conclusion was supported by a study of the development of existing exchanges. The exact location of the points of greatest traffic density was therefore first determined. In fixing the number, sites and sizes of the exchanges, an endeavour was of

TABLE No. 3

Year	Main Stations			Substations			Per 100 Inhabitants			Note
	Number	Annual Increase		Number	Annual Increase		Main Substation		Telephone set	
		Number	%		Number	%	Number	%		
1881	50	.....	....	......	....	....	...	...	...	Years of unsystematic development Reliable data for the substations are not available
1882	291	241	482	......	....	....	...	...	...	
1883	344	53	18	......	....	....	...	...	...	
1884	402	58	17	......	....	....	...	...	...	
1885	535	133	33	......	....	....	...	...	...	
1886	608	73	14	......	....	....	...	...	...	
1887	959	351	58	......	....	....	...	...	...	
1888	1,050	91	9	......	....	....	...	...	...	
1889	1,300	250	24	......	....	....	...	...	...	
1890	1,436	76	6	......	....	....	0.3	...	0.3	
1891	1,666	230	16	......	....	....	...	...	...	
1892	2,122	456	27	......	....	....	...	...	...	
1893	2,631	509	24	......	....	....	...	...	...	
1894	3,166	535	20	......	....	....	...	...	...	
1895	3,481	315	10	......	....	....	...	...	...	
1896	3,667	186	5	......	....	....	...	...	...	
1897	3,773	106	3	......	....	....	...	...	...	
1898	4,461	688	18	......	....	....	...	...	...	
1899	4,819	358	8	......	....	....	...	...	...	
1900	5,040	221	5	750	....	....	0.7	0.1	0.8	Years of quiet development
1901	5,339	299	6	837	87	13	...	...	...	
1902	5,699	360	7	972	135	14	...	...	...	
1903	6,259	560	10	1,180	208	23	...	...	...	
1904	6,926	667	11	1,379	199	18	...	...	...	
1905	7,790	844	12	1,745	366	26	...	...	...	
1906	8,999	1,209	14	2,237	492	29	...	...	...	
1907	10,227	1,228	14	2,724	487	23	...	...	...	
1908	11,441	1,214	12	3,124	400	15	...	...	...	
1909	13,024	1,683	15	3,488	364	11	...	...	...	
1910	15,020	1,996	15	4,088	600	18	1.8	0.7	2.5	
1911	17,486	2,466	16	5,288	1,200	30	...	...	...	Years during which the possibility to connect new stations to the area gradually decreased Years of economic depression
1912	18,477	991	6	6,502	1,214	23	...	...	...	
1913	20,387	1,910	10	7,615	1,113	17	...	...	...	
1914	21,311	924	5	8,427	812	10	...	...	...	
1915	21,938	627	3	8,957	530	6	...	...	...	
1916	22,684	746	3	10,157	1,200	13	...	...	...	
1917	23,502	818	4	11,220	1,063	10	...	...	...	
1918	24,717	1,215	5	12, 307	1,087	9	...	...	...	
1919	25,854	1,137	5	12,883	576	4	...	...	...	
1920	26,903	1,049	4	13,117	234	2	2.9	1.5	4.4	
1921	28,663	1,760	6	14,905	1,788	13	...	...	...	
1922	30,737	2,074	7	15,949	1,044	7	...	...	...	
1923	32,869	2,132	7	16,659	710	5	...	...	...	
1924	33,389	520	2	17,211	552	3	...	...	...	
1925	33,620	241	0.7	15,060	(−2,151x)	(−12x)	3.5	1.7	5.2	
1926	33,831	211	0.6	15,987	927	6	...	...	...	
1927 VIII 31	35,874	2,043	6	......	....	....	3.7	...	...	Cessation of economic depression

(x) Consequence of the new tariff with charges according to the number of effected conversations.

Development of Budapest Telephone Area, 1881-1926.

course made to decentralise the service as much as possible, in order to take full advantage of the automatic system in building up the area on an economic basis. Following this principle, provision was made for the erection of the necessary number of satellites in connection with the more important centres. According to numerous calculations, it was previously estimated that the number of subscribers in 1930 would be approximately 52,000; but in view of the fact that no estimate could be made of the necessary investment to meet development after the contemplated period of ten years, and further, since it was essential to ensure the possibility of connecting new subscribers continuously, the equipment was planned to carry 25% more traffic than that assumed at the end of the ten years period, that is, the exchanges will have a capacity of 52,000+25% = 65,000 lines. Moreover, it will be possible to extend the number of lines to 100,000 by extending the existing exchanges and adding further satellites without being compelled to erect new exchanges.

The network was planned on the same principle. Most of the concrete blocks, channels, the distributing conduits, and trunk cables will be installed immediately for the 65,000 line network, and the extension to 100,000 will be effected by the aid of branch cables. The frontispiece shows the location of the exchanges and the areas served by them. The present traffic is handled by Teréz exchange of 16,000 lines, the auxiliary Lipót exchange of 6,000 lines in the same building as Teréz, and the József exchange of 15,000 lines, the three manual exchanges together having a total of 37,000 lines. On completion of the network as designed, the following exchanges will be automatic:

Teréz in its original site with a capacity of..................................	20,000 lines
József in its original site with a capacity of..........................	20,000 lines
Belváros in the G. P. O. Building with a capacity of.....................	10,000 lines
Lipót on the Vaci Road in a new building with a capacity of.............	5,000 lines
Krisztina on the Krisztina Road in a new building with a capacity of....	7,000 lines
Lágymányos on the Horthy Miklós Road in a new building with a capacity of..........................	3,000 lines

TABLE No. 4

Planned capacity of the exchange	Main Exchange	Satellite	Number of stations in 1920	Increase coefficient in average	Number of stations in 1930	25% spare	Total number with spare	In comparison of the planned capacity						
	Name of the exchange							Available		Excess		Real spare in %		
								Station	%	Station	%	Main exch.	Satellite	Total
20,000	Teréz		8,820	1.81	16,257	4,063	20,320			320	1.6	23.4		23.4
16,000	József		7,134	1.82	12,985	3,245	16,230			230	1.4	23.6		
800		Zugló	217	3	651	163	814			14	1.8		23.2	
1,000		Köbánya	304	2.5	760	190	950	50	5				30	
800		Kispest	153	3.7	566	142	708	92	11.5				36.5	
1,400		Pesterzsébet	290	3.7	1,073	269	1,342	56	4				29	
4,000		Zugló Pesterzsébet	964		3,050	764	3,814	186	4.6				29.6	
20,000	József	Zugló Pesterzsébet	8,098		16,035	4,009	20,044			44	0.3			24.7
10,000	Belváros		4,646	1.78	8,252	2,063	10,315			315	3.2	21.8		21.8
3,600	Lipót		926	2.5	2,318	576	2,894	706	19.4			35.6		
1,400		Ujpest	436	2.5	1,090	273	1,363	37	2.6				27.6	
5,000	Lipót	Ujpest	1,362		3,408	849	4,257	743	14.8					39.8
4,000	Krisztina		1,914	1.82	3,488	871	4,354			354	8.9	16.1		
1,000		Vár	419	1.82	763	191	954	46	4.6				29.6	
600		Svábhegy	150	3	450	113	563	37	6.1				31.1	
600		Zugliget	153	3	459	115	574	26	4.3				29.3	
800		Obuda	326	1.82	593	149	742	58	7.2				32.2	
3,000		Vár Obuda	1,048		2,265	568	2,833	167	5.5				30.5	
7,000	Krisztina	Vár Obuda	2,962		5,748	1,439	7,187			187	2.7			22.3
2,600	Lágymányos		668	3	2,004	501	2,505	95	3.7			23.7		
400		Budafok	104	3	212	78	390	10	0.3				25.3	
3,000	Lágymányos	Budafok	772		2,316	579	2,895	105	3.5					28.5
65,000	Total:		26,660		52,016	13,002	65,018			18	0.03			24.97

Proposed Extension of 65,000 Line Budapest Exchange Area.

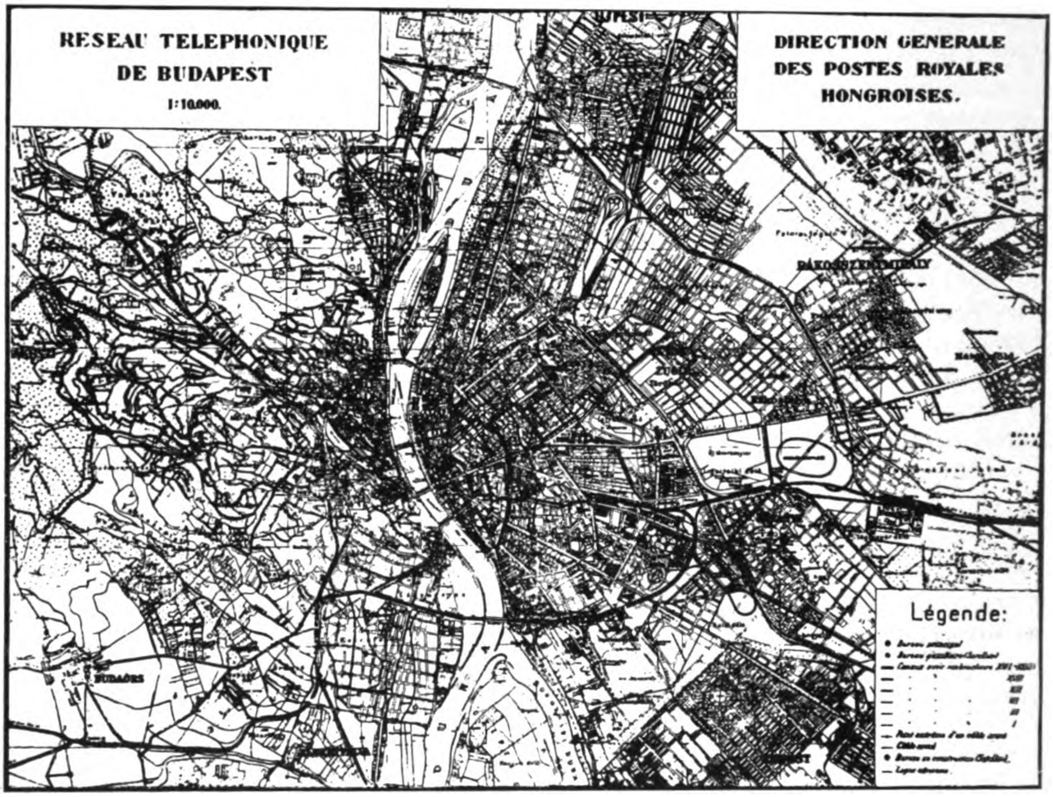


Figure 2—MAP OF BUDAPEST

When this project has been completed, there will exist in the Budapest Telephone Area six automatic exchanges which, taken together, will have a capacity of 65,000 lines. The Belváros and Teréz exchanges will operate as complete and independent units. The Krisztina exchange will have four satellites; Vár in the Home Office buildings, with a capacity of 1,000 lines; Svábhegy in a new building, with a capacity of 600 lines; Zugliget in a new building, with a capacity of 600 lines; and Obuda in a new building with a capacity of 800 lines.

The József exchange will have four satellites: Zugló in a new building with a capacity of 800 lines; Köbánya in a new building with a capacity of 1,000 lines; Kispet in a new building with a capacity of 800 lines; and Pesterzsébet in a new building, with a capacity of 1,400 lines.

The Lipót exchange will have one satellite, Ujpest in a new building, with a capacity of 1,400 lines. The Lágymányos exchange will have one satellite, Budafok, in a new building, with a capacity of 400 lines. The capacities of the satellites are of course included in the capacities of the main exchanges. The geographical layout is supplemented by Table No. 4, which indicates the capacity of the main exchanges and satellites of the 65,000 line area, the distribution of subscribers, and the percentage of spare lines. Table No. 5 gives a general summary of the exchanges of the 100,000 line area. From this figure it is clear that it is not intended to set up new exchanges, so long as the five-digit exchange system is not fully exploited, but new primary and secondary satellites will be added as required.

Figure 2 shows the layout of the Budapest area. It must be mentioned that an essentially underground system will be provided with con-

TABLE No. 5

Main Exchange	Satellite, Name and Place: Primary	Satellite, Name and Place: Secondary	Capacity 65,000 Lines: Detailed	Capacity 65,000 Lines: Total	Capacity 100,000 Area: Detailed	Capacity 100,000 Area: Total	First figure of the calling numbers	Exploitation (main lines)
Teréz			20,000	20,000	20,000	20,000	1 and 2	20,000
József			16,000		16,000			
	Zugló		800		800			
	Köbánya		1,000		1,000			
	Kispest		800		800			
	Pesterzsébet		1,400	20,000	1,400	20,000	3 and 4	20,000
Belváros			10,000	10,000	10,000	10,000	8	10,000
Krisztina			4,000		8,000			
	Svábhegy		600		1,000			
		Farkasrét(x)			500			
		Budaörs(x)			500			
	Zugliget		600		1,000			
		Budakeszi(x)			500			
		Hidegkut(x)			500			
	Obuda		800		2,000			
	Vár		1,000		2,000			
	Tabán(x)				2,000			
	Naphegy(x)			7,000	2,000	20,000	5 and 6	20,000
Lipót			3,600		6,000			
	Ujpest		1,400		2,000			
	Angyalföld(x)				1,000			
		Rákospalota(x)		5,000	1,000	10,000	9	10,000
Lágymányos			2,600		6,000			
	Budafok		400		1,000			
	Kelenföld(x)				2,000			
		Tétény(x)		3,000	1,000	10,000	7	10,000
For stations of service or other special purposes						10,000	0	10,000
Total:				65,000		100,000		100,000

(x) Refers to the extension from 65,000 up to 100,000 lines.

Numerical Capacity of the Budapest Telephone Area. (5-Figure System.)

crete block channels, distributing conduits, lead-covered paper-insulated cables or armoured cables of from 600 down to 26 pairs of conductors. In the fully developed town districts the overhead lines will totally disappear and will remain only in the suburbs, although even here they will be very much restricted. At present the number of subscribers served by underground cables is 30,000, and at the time of the cut-over of the first automatic exchange, this will increase to 35,000.

Choice of the Automatic System

It will be appreciated that in the early planning stages the question of choice of a particular automatic system could be disregarded, but a point has been reached in the present exposition where it becomes necessary to discuss problems with which the choice of a system is closely connected. It is a fact that the Hungarian Postal Administration studied automatic exchanges as far back as 1908. In 1913 and again in 1922, engineers were sent out to investigate the subject in various European towns, and detailed reports by experts were produced on their return. Finally, in 1924, the Administration investigated all the particulars of the question once more, and on that occasion the delegate (the writer of this article), who drew up the development plans, studied various working automatic exchanges and the factories manufacturing the equipment in Austria, Germany, Belgium, Switzerland and Holland, and further secured full information from London and Paris where the Administrations were engaged in selecting an automatic system. In arriving at the final decision, the following salient points were taken into consideration:

1. Technical perfection.
2. Reliable service.
3. Freedom from disturbance in gradual transition from manual to automatic working.
4. Flexibility and adaptability to special requirements.
5. Economical exploitation.
6. Facility of extension.
7. Simple and economical maintenance.
8. Fostering of home industries.
9. Manufacturing expenses—first cost.

Taking all these points into account, we came to the conclusion that the systems based on the principle of direct control of the selectors were not suitable for our purpose, the chief reason being that the rigid numbering scheme would not permit of ready adaptation to varying traffic conditions. It would be beyond the scope of this article to compare the advantages and disadvantages of the various systems, but in support of the decisions it might be mentioned that in those places where direct control systems have been adopted, certain auxiliary equipments have been employed by means of which the systems have really been converted to indirect control. As an example we would mention the Director System adopted for the London area by the British Post Office. If it is agreed to reject the principle of direct control, i.e., that the selectors must not be operated directly by impulses originated by the subscriber, it becomes unnecessary to accept the 100-point type of selector used in such a system. This selector must be of light construction, and is rigidly bound to the decimal system of numbering. On the contrary, selectors can be employed of more robust construction having as many contacts in the bank as economically expedient, thus making larger groups possible. The movements of such a selector are not controlled by the comparatively weak impulses originated by the subscriber (which impulses vary according to the characteristics of the subscriber's line), but by common power drive mechanisms through the medium of the apparatus used for receiving, storing and retransmitting the initial impulses. These pieces of apparatus might be called "registers," "senders," or any other name. The control of the selectors is not only indirect in the above sense, but also acts on the revertive principle, because the impulses are stored by the senders and transmitted as the selectors are free to receive them, the condition of the selector thus governing the transmission of the impulses from the sender. The objection may of course be raised that power-driven systems necessitate the use of transmission equipment, and that selectors having a capacity of more than 100 lines involve re-numbering. This reasoning does not affect the main issue of better service, since it does not alter the numerous advantages arising from the use of more robust switches of greater capacity and a system with facilities for translation.

Last, but not least, the fact that 200 and 300 point selectors are used, is an advantage by which the area can be increased from the designed 65,000 lines to 200,000 lines, without inserting the fourth selector.

At the time when choice had to be made between the systems, only the Panel System of the Western Electric Company, and the Rotary System of the International Standard Electric Corporation possessed the advantages that we have briefly outlined. The then newly developed Swedish Ericsson System had not been in practical use. (The first exchange of this type was cut-over in Rotterdam in the spring of 1924). The Panel System, having been planned for cities much larger than Budapest, was not considered suitable for the purpose; none of the larger cities in Europe had adopted this system, as it is designed for a capacity of 1,000,000 subscribers.

Three Hungarian manufacturers tendered for the erection of exchanges of Standard Electric Rotary, Strowger and Ericsson systems, respectively. The Administration recommended to the Hungarian Government the Rotary System, which has already proved very satisfactory at the Hague, Zurich, Antwerp, Brussels and elsewhere. The Administration were also influenced in their decision by the fact that only the United Incandescent Lamps and Electrical Company, Limited, and the Hungarian licensee of the International Standard Electric Company could guarantee that at least 80% of the equipment would be manufactured in Hungary. The justice of this decision was confirmed by the fact that Paris, Oslo, Copenhagen, Bucharest and Madrid have since all adopted the Standard Electric

Rotary System. In addition, it is in use in other cities of France, Norway and Spain, as well as in Australia, Belgium, China, Czecho-Slovakia, the Dominican Republic, Great Britain, Holland, Hungary, Italy, Mexico, New Zealand, Poland, South Africa and Switzerland. There are approximately three-quarters of a million lines of Standard Electric Rotary equipment in service or on order.

General Requirements for Automatic Exchange Service

Requirements which automatic exchanges have to fulfill, according to the general conditions specified by the Postal Administration, are:

1. At the partial or total cut-over of the automatic exchanges, facilities must immediately be provided and maintained to enable all subscribers of the area to call each other and talk with each other without hindrance for an unlimited period, whether they are connected to an automatic or to a manual exchange.
2. Undisturbed toll facilities for all subscribers in the area.
3. The automatic equipment must be suitable for installation of party lines at any future time.
4. A subscriber connected to an automatic exchange, if calling an automatic or manual subscriber, is not to have anything else to do than to lift his receiver and then dial the wanted number by operating the dial mounted on his telephone set. Connecting and ringing, release, busy signalling, metering, etc., must be performed automatically.
5. After lifting his receiver, the calling subscriber must get a special tone signal which indicates that his line is connected to a free register.
6. If the calling subscriber does not get connection immediately, because all connecting circuits or group selectors are engaged, the connection has to take place without the renewal of the call according to the principle of continuous hunting.
7. A tone signal must be given to the calling party at the commencement of the transmission of ringing current to the called party's bell.
8. Ringing must continue with regular intervals until the called party answers, and must then stop immediately.
9. If called party's line is busy, calling party must receive a regularly interrupted busy tone.
10. Noises which disturb the conversation, or jarring sounds must not be heard in the receivers during the connecting process, and connections between two parties engaged in conversation must be free from this trouble.
11. Release must take place automatically when the calling party replaces his receiver. All apparatus engaged in the connection must return to the home position.
12. At the end of the conversation the calling party must become free, even if the called party does not replace his receiver, that is, if the connection in the final circuit is not broken down. In this case an alarm signal must be given to the maintenance staff of the exchange, who shall restore the final selector to normal.
13. Effective connections must be metered at the end of conversation. Should the Postal Administration wish to charge for the conversations according to certain periods of time, the metering equipment must be capable of providing for repeated metering at certain intervals.
14. Special calls—toll recording operator, complaints operator, telegrams, fire, first aid, police—must not be metered.
15. One and the same number must serve for the calling of the called party, even if the latter has more than one station, that is, the exchange equipment has to be made so that the calling party shall be able to get connection with one free station by dialling the one calling number and shall receive the busy tone signal only when all the stations of the called party are engaged.
16. P. B. X. operators must be able to call directly every station in the area and vice versa.
17. The exchange maintenance staff must receive a signal if a call originates for a subscribers' station which is not yet connected, or is temporarily disconnected, or is recorded as defective, or has changed its calling number, or can be called only by name.
18. The exchange maintenance staff must receive a signal when a calling subscriber lifts his receiver, but does not dial any number, or when subscribers' lines are on contact or short circuited. Such faulty calls are not allowed to engage a register for too long a period; the registers must become free automatically after an interval of 30 seconds from the taking of the register.

19. The exchange maintenance staff must receive a signal if a subscriber in the area does not get connected on account of circuit failure. The calling subscriber must be released from the defective circuit automatically and obtain a new connection circuit and register without replacing his receiver and lifting it again. The defective circuit and all circuits which are connected with it must remain in the condition in which the defect occurred, to enable the maintenance staff to ascertain the nature of the fault.

20. All the principal circuits necessary for building up a connection must be capable of being disconnected electrically from all other circuits, and switched over to a routine test circuit for the purpose of seeking and correcting faults.

21. All necessary monitoring, checking and supervisory equipments must be provided for the determination and prevention of faults, the breaking down of abnormal connections, and the most economical distribution of traffic between the several groups of machines, and must enable the supervisory staff of the exchange to speak personally with the subscribers in case of faulty dialling. The equipments of the wire chiefs' desks, monitoring desks, supervisory desks, and service observation desks, as also the several alarm and time alarm equipments, serve these purposes.

22. Alarm signals are necessary in the following cases:

(a) Short circuits.
(b) Blown fuses.
(c) Irregular functioning of selectors from whatever cause.
(d) Ringing current failure.
(e) Main current failure.
(f) Incorrect operation of rack motors.
(g) Defective dialling by subscribers.

If no night service is given at the exchange, it must be possible to switch the alarm signals over during the night to the person responsible for supervision.

23. Test jacks must be provided on the distributing frames and racks.

24. Facilities must be provided for jumpering the subscribers' lines, trunk lines and connection circuits to suit traffic conditions.

25. Charts must be provided on the switchrack to show the numbers of the switches and the incoming and outgoing ends of the trunk lines, to enable the maintenance staff to trace the connections without difficulty.

Gradual Transition from Manual to Automatic Service

Instead of the three manual exchanges now in use in Budapest, six automatic exchanges and ten satellites will be installed. Technical reasons, and moreover reasons of finance, necessitate a gradual transition to the full automatic area, so that during the period of transfer combined automatic and manual connections will have to be effected. Transitional equipment therefore is necessary to handle the traffic between the manual and automatic offices in the simplest and best way.

(a) *First Stage.*

The first stage in the automatic installation programme consists of the replacement of Teréz manual exchange, the capacity of which (16,000 lines) is exhausted. The area served by Teréz exchange comprises departments IV, V, and VI, on the left bank of the Danube, where the business activity is concentrated, and nearly all the districts on the right bank of the Danube. Therefore, in the first stages of the project provision must be made for automatic service to this section of the town area.

After completion of the first stage, which is already under installation, three main exchanges are to be cut into service:

1. Krisztina main exchange with:	
Vár Obuda Svábhegy Zugliget	Satellites – 6,000 main lines.
2. Belváros main exchange	10,000 main lines.
3. Teréz main exchange –	10,000 main lines.
Total – – –	26,000 main lines.
Manual exchanges still in use:	
(1) József with – – –	15,000 main lines.
(2) Lipót with – – –	6,000 main lines.
Total – – – –	21,000 main lines.

Thus the capacity of the area will be 47,000 main lines.

The following principles govern the provision of service in this area:

(*a*) A subscriber on an automatic exchange must be able to get connection automatically with every subscriber in the area whether the called subscriber belongs to an automatic or a manual exchange.

(*b*) Calls incoming from an automatic to a manual exchange must—in accordance with (*a*)—be directed to a requisite number of group and final selectors installed in the manual exchanges and not to operators. For this purpose the terminals in the arcs of the final selectors have to be connected to the manual multiple of the corresponding called numbers.

(*c*) Connections between subscribers on manual exchanges have to be effected in the normal manner.

(*d*) Calls incoming from a manual to an automatic exchange have to be handled by a semi-automatic method. Such calls arriving at the manual "A" positions are directed by the operators to the semi-B positions installed in their own exchange, the semi-B operators completing the connections by means of digit keys. These manual exchanges have to be equipped with finders to hunt for the calling semi-B positions, and with registers and group selectors to effect the connections controlled by the semi-B positions.

As a result of such an arrangement, the connections of the subscribers on the automatic offices are uniform, and these subscribers are not obliged to ask for manual exchanges. Further, there is no necessity of installing costly equipments which would be of a transitional character and which would have to be discarded after completing the automatic area. The installation of carriage call indicator equipment for the calls incoming from automatic exchanges to manual exchanges was not considered advisable. There are no spare B boards having a suitable multiple which could easily be altered for this purpose, and the installation of new boards would be very costly, considering that they are only required temporarily.

All solutions which would entail the installation in the automatic offices of manual switchboards, even of a temporary character, for the calls incoming from the manual offices, were rejected. It was therefore decided that the most suitable solution of the problem of dealing with incoming automatic traffic is to employ group and final selectors in the manual exchanges where the necessary space is available. These can be put to good use when the exchange has been converted to automatic. It is true that such an arrangement considerably increases the expense of the initial stage, but this increase will be offset by the fact that in the following stages, 35% to 40% of the switches needed for the automatic installation will be already available. There were several reasons for using separate semi-B positions instead of giving the "A" operators dialling facilities. It is true that the dialling does not considerably increase the operators' load (the coefficient for a five-digit call is increased from 1.5 to 1.75), and it is undoubtedly a great advantage that the connection can be established by the operator who receives the call. However, it did not seem reasonable to train operators in the use of the dial, besides which local conditions were not suitable for the fitting of dials on the manual boards. This is more particularly the case at Teréz exchange where during the gradual transition period it is necessary to ensure uninterrupted operation, and where the installation of dials on key-boards already overloaded with accessories would be almost impossible, and in any case very costly, considering the short time the equipment would be needed. It has therefore been decided that the installation of semi-B positions at Lipót exchange, which is located in the same building as Teréz, would be the more convenient arrangement. These semi-B positions, the quantity of which is governed by ultimate traffic considerations, will handle the traffic outgoing to automatic from Teréz without difficulty during the short period of cutting over from manual to automatic. When Teréz manual office has been entirely replaced, these semi-B positions will be used only for the automatic traffic outgoing to Lipót exchange which will still be in commission.

In connection with the first stage, arrangements were made to provide the new 400 line toll exchange which is to be equipped with automatic facilities and installed simultaneously with the automatic exchanges. To ensure uniform loads on the recording operators' positions, automatic call distributors are embodied in the scheme. Key sets are to be provided at the toll line positions to enable toll calls to automatic subscribers to be completed direct. This has involved provision for the requisite number of line finders, trunk finders and register finders in connection with the toll board circuits. Figure 3 shows the connections between the automatic exchanges and the connections between them and the local manual exchanges and toll exchange.

With regard to the location of the exchanges already dealt with, it may be pointed out that on account of local conditions Teréz exchange,

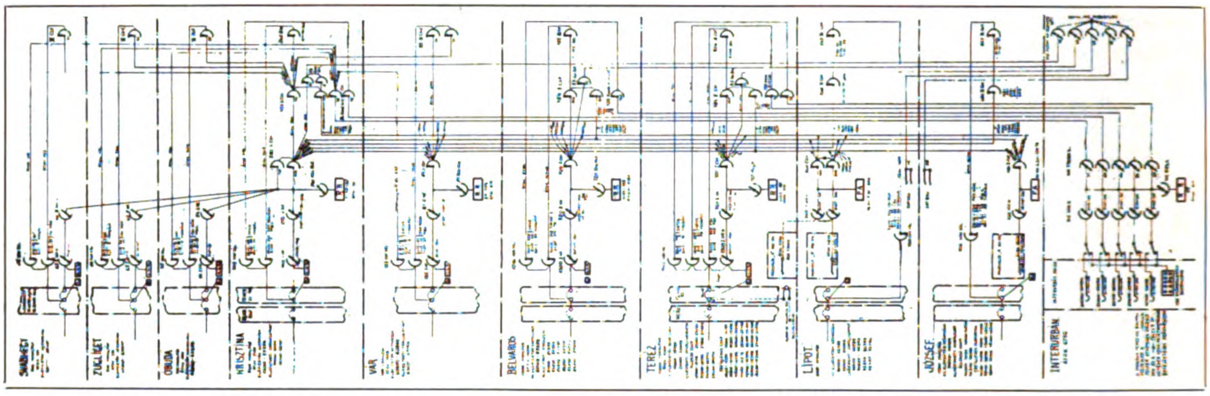


Figure 3—Diagram of Connections of All Exchanges (Automatic, Manual, Toll). First Stage, 47,000 Lines.

which will have an ultimate capacity of 20,000 lines, will be installed with only 10,000 lines during the initial stage, and on a provisional site. The 20,000 line exchange will be permanently installed in the present Teréz manual switching room which will not become available until the manual exchange has been replaced. In the latter stages, the provisional 10,000 line Teréz automatic exchange will be removed, and its automatic equipment utilised for the new exchanges under installation.

The main and intermediate distributing frames, as well as message register racks, cabling and power plant, will be designed for the requirements of the 20,000 line exchange, and installed at once in their final positions.

(b) *Second Stage.*

The first part of the programme will be completed with the replacement of Teréz manual exchange by automatic equipment. The next stage consists of the following:

1. Complete installation of Teréz 20,000 line exchange quite independently of the provisional exchange of 10,000 lines. This will result in 10,000 new lines.
2. Installation of Lipót 3,600 line automatic exchange and its 1,400 line satellite Ujpest, making in all 5,000 lines.
3. Extension of the automatic equipment at József manual exchange for the incoming automatic traffic, and of its semi-automatic equipment for the traffic outgoing to automatic. These extensions will be carried out to meet the requirements of the 65,000 line area.

After the cut-over of the new automatic exchanges mentioned under items 1 and 2, the provisional 10,000 line automatic equipment at Teréz and Lipót manual exchanges will disappear, their automatic equipment being available for the next automatic installation. At the end of the second stage the area will have 41,000 automatic lines. Of the manual exchanges, József

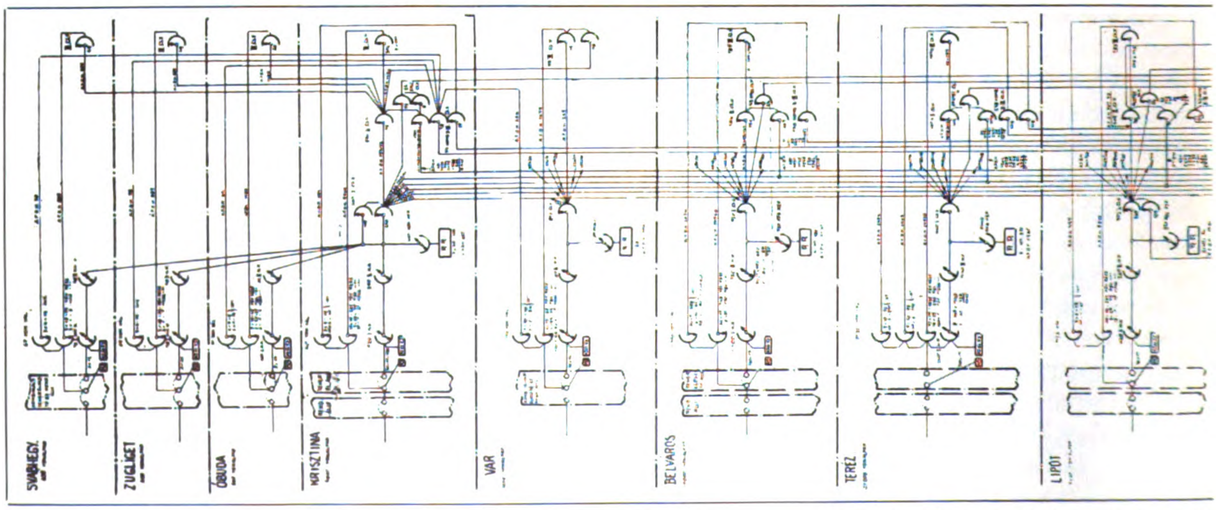


Figure 4—Diagram of Connections of All

exchange, having 15,000 lines, will then alone be in service. The total capacity of the area will therefore be 56,000 lines.

(c) *Third Stage.*

In this period the automatic equipment recovered from the closed exchanges will be employed as follows:

1. Installation of the 2,600 line Lágymányos exchange and its 400 line satellite Budafok, a total of 3,000 new automatic lines.
2. Extension of Krisztina main exchange to 4,000 lines and each of its satellites amounting to 7,000 lines; an extension of 1,000 lines.

The automatic equipment of the József manual exchange remains unchanged, because it attained its capacity under the 65,000 line area scheme in the second stage. The total capacity of the area is thus 60,000 lines, 45,000 of which are automatic.

(d) *Fourth Stage.*

The area of the automatic exchanges indicated above, overlaps the districts belonging to József manual exchange, so that ultimately only one manual exchange of reduced capacity remains to be converted to automatic. This has to be carried out in two parts, to facilitate an economical use of the available premises.

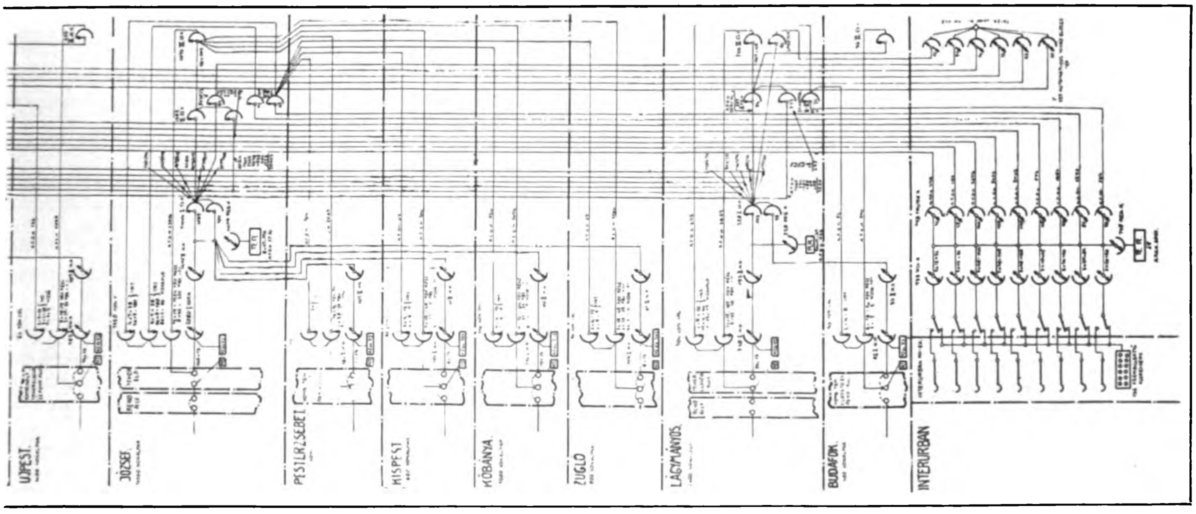
1. First, the subscribers' telephone sets have to be equipped with dials, and the automatic exchange equipment extended so that the subscribers on József exchange will be able to secure connection with every subscriber connected to any other exchange in the area, in exactly the same manner as the automatic subscriber. At the same time trunk circuits must be connected to the levels of the first group selectors reserved for the traffic to József, each trunk leading to the "A" operators who receive the local calls. If a József subscriber calls a subscriber on the same exchange, he has only to dial the first digit of the number of the called subscriber, thereby securing the services of the "A" operator who establishes the required connection. Thus the semi-automatic boards become superfluous because both incoming and outgoing automatic traffic is handled on a full automatic basis.
2. Finally, the quantity of the third group selectors and final selectors must be increased so that not only the incoming and outgoing traffic, but local calls also can be handled automatically, as well as the switching of the incoming toll calls. In connection with this work, the satellites Zugló, Köbánya, Kispest and Pesterzsébet are to be completed, after which the József manual subscribers will be cut over to József automatic exchange and its satellites. This completes the full automatic area, all the manual exchanges disappearing. The attached junction diagram, Figure 4, shows the connections in the 65,000 line automatic area.

Numbering System

In the choice of the numbering system the guiding points have been:

1. To reduce the change of existing numbers as little as possible.
2. To enable the automatic subscriber to call every other subscriber of the area, whether automatic or manual, by direct dialling.
3. That after the 5-digit numbers become insufficient, the only change in numbering will be to add a sixth digit or a letter before them.

As the numbers in the existing Teréz, József and Lipót exchanges differed only in the letters T, J, and L put before them, it was necessary to change the numbers of existing lines in a simple



Exchanges. Second Stage, 65,000 Lines.

way. Considering this, the numbers over 10,000 in the Teréz exchange were left unchanged, and 20,000 was added to the numbers 0 to 9,999. In this way, Teréz exchange was given the numbers 10,000 to 29,999. The new numbers of the József exchange were derived by adding 30,000 to the old ones, so that the subscribers of this exchange obtained the new numbers 30,000 to 49,000. Applying the same method to the Lipót exchange, 90,000 was added to the old numbers; in consequence, the new numbers have the group numbers 90,000 to 99,999. This simple and general change of the numbering was made before the introduction of automatic service; by this means, during the gradual transition to automatic service, there was a change of number only in the case of subscribers who were to be transferred to the new automatic main exchange: Krisztina, Belváros and Lágymányos, or their satellites. The numbers beginning with 0 were not given to subscribers, but were used on special services—complaints, toll recording, fire station, ambulance, police, service supervision, etc. This enabled those services to be called by dialling two figures, 01, 02, 03, 04....09.

TABLE No. 6

Levels of I. group Selectors	NUMBERING		Name of Exchange
	I. 5 digit numbers (up to 99,999 lines)	II. 6 digit numbers (over 100,000 lines)	
1	01,02... etc. for special calls	01,02... etc. for special calls	
2	90,000 - 99,999	200,000–209,000 290,000–299,999	Lipót
3	80,000 - 89,999	170,000 - 189,999	Belváros
4	70,000 - 79,999	270,000 - 289,999	Lágymányos
5	50,000 - 69,999	150,000 - 169,999	Krisztina
6		250,000 - 269,999	Reserved for Future Exchange
7	30,000 - 49,999	130,000 - 149,999	József
8		230,000 - 249,999	Reserved for Future Exchange
9	10,000 - 29,999	110,000 - 129,999	Teréz
10		210,000 - 229,999	Reserved for Future Exchange

Distribution of the Numbers on the Levels of the First Group-selectors.

The numbering system described above, i.e., the distribution of the numbers on the levels of the first group selectors, is shown in Table No. 6, both for the use of 5-digit numbers up to 99,999, and for the use of 6-digit numbers up to 299,999.

Switch Calculations of Automatic Exchanges

The basis of the switch calculations of the exchanges in the 65,000-line area was as follows:

(a) *Exchanges of the 65,000 stage*	*Number of Lines*
Krisztina area, automatic	7,000
Teréz exchange, automatic	20,000
Lipót area, automatic	5,000
József area, automatic	20,000
Lágymányos area, automatic	3,000
Belváros exchange, automatic	10,000
Total	65,000

The distribution of lines in the various areas is:

(1) *Krisztina area.*	
Krisztina automatic main exchange	4,000
Vár automatic satellite	1,000
Obuda automatic satellite	800
Zugliget automatic satellite	600
Svábhegy automatic satellite	600
Total	7,000
(2) *Lipót area.*	
Lipót automatic main exchange	3,600
Ujpest automatic satellite	1,400
Total	5,000
(3) *József area.*	
József automatic main exchange	16,000
Köbánya automatic satellite	1,000
Zugló automatic satellite	800
Kispest automatic satellite	800
Pesterzsébet automatic satellite	1,400
Total	20,000
(4) *Lágymányos area.*	
Lágymányos automatic main exchange	2,600
Budafok automatic satellite	400
Total	3,000

(b) *Estimated average busy-hour calls per line.* 1.5

(c) *Average holding time of a local connection.* .... 2 minutes

(d) Estimated average busy-hour calls to toll recording in the calculation of the local equipment 0.05

(e) *Average holding time* of a call to toll recording . 1 minute

(f) *Average busy-hour* calls to toll recording per line referred to a holding time of 2 minutes, $\frac{1}{2} \times 0.05$ 0.025

Note: The 1.5 average busy-hour calls include this 0.025, consequently the average busy-hour calls beginning from the second group selectors are 1.5—0.025 . . 1.475

(g) *Average holding time of the registers* .... 25 seconds.

(h) We suppose that the calls outgoing from an exchange are distributed among the various exchanges in the relation of their number of lines.

(i) The traffic of other special calls, as complaints, telegram-service, wire-chief, is considered only in the calculation of the number of group selectors for special calls.

(k) The first line-finders, cord-circuits, toll circuits, and the trunk lines to toll recording, are calculated on the probability basis............... P = 0.001
Registers on the basis............. P = 0.0001
Group and final selectors.......... P = 0.01
Detailed calculations were then made for the equipment required for local calls, special calls, and toll connections.
In the calculation of the semi-B positions required in the first stage, it was supposed that an operator could handle 340 calls in the busy hour and give good service. In actual practice expert operators can master 450-500 calls an hour in these positions. Every semi-B position has 20 trunks.

Equipment. The automatic exchanges of the local Budapest telephone area are equipped with 100 point finders of the latest type, with 300 point group-selectors, 200 point final selectors, and with horizontal type sequence switches—all gear driven. The registers are of the all-relay type.

Circuit connections of the exchanges are shown in Figures 3 and 4.

Automatic Main Exchanges. The calls of the subscribers of the automatic main exchanges are directed on first line-finders and cord-circuits. The cord-circuits include second line-finders, first group-selectors, and register-choosers.

The distribution of the calls to the various main exchanges or areas is made from the first group-selectors, the ten levels of which correspond to ten directions. The other group-selectors, i.e., second group-selectors, third group-selectors, and the final selectors, together with the first group-selectors, are controlled, during building up of the connections, by the register.

Groups of final selectors with 300 lines are provided as P. B. X. (Private Branch Exchange) Finals. Of these 300 lines, only 200 have numbers in the numbering system; the 100 further lines have no numbers, being used as second, third, etc., lines of the P. B. X. group.

Automatic Satellite Exchanges

There are three different types of automatic satellites:

(1) Of the first type are: Obuda, Zugliget, Svábhegy, Ujpest, Budafok.
(2) Of the second type are: Kabanya, Zugló, Kispest, Pesterzsebet.
(3) Of the third type is: Vár.

The first two types are similar in that the calls originated by their subscribers are taken up by first and second line-finders in the satellite, and directed on to first group-selectors in the main exchange.

The incoming calls to satellites (including the calls originated in the same exchange) are directed, in the first type, from the second group-selectors in the main exchange on to third group-selectors in the satellite; but in the second type, the third group-selectors are still in the main exchange, and the satellites are equipped with final selectors only.

The Vár satellite has, from the point of local and outgoing calls, the feature of a main exchange, i.e., it has local cord-circuits and registers, with the difference that the local calls, corresponding to the line capacity 2,000 are directed from the first group-selectors on to the third group-selectors—the second group-selectors stage being omitted. With regard to incoming calls, the Vár satellite has the same feature as the first type, i.e., all incoming calls are directed from second group-selectors in the main exchange to third group-selectors in the Vár satellite.

Among the satellite final selectors there are also P. B. X. groups, containing 300 subscribers' lines, to be used in the same manner as in the main exchange.

Automatic Toll and Other Special Equipment

1. The toll operator is enabled to connect to the subscribers of the automatic exchanges by plugging into an individual jack corresponding to the automatic main exchange or area containing a 10,000 group of subscribers. The selected jack is picked up by a line-finder, a register-chooser connects an idle register, and a trunk-finder extends the line to the corresponding area. It is to be noted that as the area is determined by the jack chosen, the first group-selector may be left out and the call directed to a combined second and third group-selector in the automatic main exchange. On each level of these combined second and third group-selectors there are five groups of trunks each containing six trunks leading to a certain 200 subscribers' group of final selectors, i.e., the group-selector selects on each level a group of 1,000 subscribers, therefore the ten levels correspond to a group of 10,000 subscribers. Accordingly, the group-selectors of a

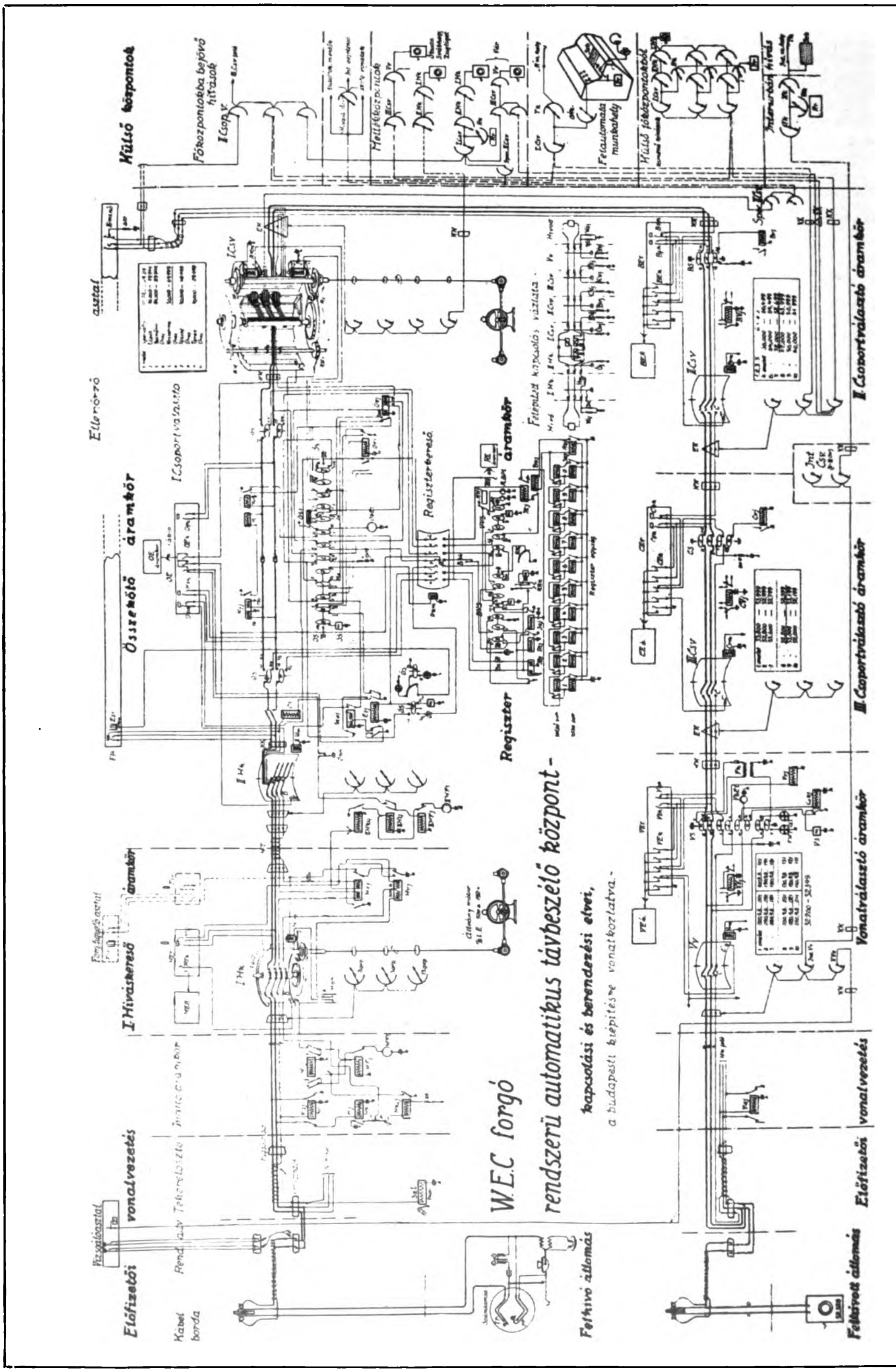


Figure 5—Circuit Schematic of the Automatic and Semi-Automatic Exchanges.

20,000 line area work in two main groups.

If the subscriber of a satellite exchange is wanted on a toll connection, then the call is directed from combined second and third group-selectors in the main exchange to final selectors in the satellite. The toll circuits are independent of the local circuits, and are connected with them only on the arc of the final selectors. The toll connections have preference over local connections, and the toll operator is enabled to break down an existing local connection.

If the last line of a P. B. X. group is busy in a toll connection, the electrical conditions of the line before the last are changed in such a manner that if a second toll call arrives, the final selector does not step on to the last line, but stops on the line before the last, and the operator, who breaks down the local connection existing on this line, then accomplishes the toll connection.

2. The toll recording positions are reached by all subscribers dialling two digits (01). In these calls the first group-selector selects, on its first level, an idle special second group-selector, and this second group-selector selects on its tenth level an idle trunk to the toll exchange, where the trunk ends in a call distributing switch which hunts for a free position.

The calls to toll recording, originating in the Vár satellite, go a different way, as the first group-selector selects on its fifth level an idle trunk to the Krisztina exchange where the incoming second group-selector selects on its tenth level an idle special third group-selector, and this third group-selector works in a manner similar to the special second group-selector in the former case.

3. The other special calls, complaints (03), telegram-service (02), reports of linemen (09) are operated in a way similar to the calls to toll recording, with the only difference that corresponding to the second digit, the calls are directed to trunks on different levels of the special group-selector.

Detailed description of equipment and operation of circuits would lead too far. A short summary of the equipment used for control, test and supervision may, however, be useful.

In the main exchanges there are the following control, supervision, and test desks:

(a) *Monitoring Desk.* For a maximum of 10,000 lines, two positions with the following equipment:
  (a.1) Line jacks of the outgoing trunks for testing purposes.
  (a.2) Lamps and jacks of the cord circuits for P. G. (permanent glow) calls.

This equipment is provided to release the register, and to give a signal to the maintenance personnel from the cord-circuit when the call fails to get through on account of a line-fault, or the subscribers' mistake.

  (a.3) Lamps and jacks of the dead line circuits.
  (a.4) Lamps and jacks of the dead level circuits.
  (a.5) Lamps and jacks of automatic lines for incoming service calls.
  (a.6) Jacks of automatic lines for outgoing service calls.
  (a.7) Lamps and jacks of direct service lines.
  (a.8) Voltmeter circuit for trunk testing.
  (a.9) Busy lamps of second line-finder groups.
  (a.10) On each position:
    4 monocord circuits.
    2 double cord circuits.
    1 test plug of the voltmeter test circuit.

(b) *Lamp Frame.* 1 unit for maximum 10,000 lines near the monitoring desk, with the following equipment:
  (b.1) 1 lamp for each cord-circuit.
  (b.2) 1 key and 1 lamp for each register. When the key is operated, the cord-circuit lamp glows and indicates the cord attached to this register. If the connection fails to go through on account of some circuit-fault, the lamp of the cord-circuit taking part in the connection, flickers. The circuits engaged in this connection are held over, but the calling subscriber is released and gets a free register again. If the calling subscriber does not hang up his receiver at the end of the conversation, the cord-circuit lamp glows.

(c) *Service Observation Desk.* The service observation desk provides for the following:
  (a) Observation of the connecting phases and duration of calls originated by subscribers.
  (b) Control of any register-circuit.
  (c) Metering of the number of calls and call minutes going through any circuit-section.
  (d) To make experimental calls to find the quality of the exchange-service.
  (e) Observation of calls originated by or directed to certain subscribers, in the case of complaints.
  (f) Registering the number of times all circuits of a group are busy.

The parts of this equipment are:

  (c.1) Service observation circuit for the observation of the traffic of 2 x 14 = 28 first line-finder circuits.

(c.2) Service observation circuit for the observation of five register circuits.
(c.3) Concentration of all alarm-signals.
(c.4) Registering-ammeter with the possibility of connection with any section of group—or final—selector circuits for registering the conversation-minutes going through the section.
(c.5) Outgoing automatic service lines.
(c.6) Incoming automatic service lines.

(d) *Supervisor's Desk.* The supervisor's desk, a specialty of Budapest, is equipped as follows:

(d.1) Lines under supervision.
(d.2) Lines to be called with number and name.
(d.3) Lines to be called with permission only.
(d.4) Disconnected lines.
(d.5) Transferred lines.
(d.6) Lines with number changed, not contained in the directory.
(d.7) Disconnected line circuits, their numbers given to other subscribers.
(d.8) Incoming automatic service lines.
(d.9) Outgoing automatic service lines.
(d.10) Direct service lines.

(e) *Wire-chief's Desk.* The wire-chief's desk, up to 10,000 lines, 1 or 2, two-position desks equipped as follows:

(e.1) Test final circuits.
(e.2) Test-lines to the M. D. F. (Main distributing frame).
(e.3) Lamps and keys for special complaint-calls.
(e.4) Lamps and keys for special calls of linemen.
(e.5) Incoming automatic lines.
(e.6) Outgoing automatic lines.
(e.7) Direct service lines.
(e.8) Lamps and keys of dial testing circuit.
(e.9) Busy lamps of the first line-finders groups.
(e.10) Each position has:
1 voltmeter test circuit.
1 double cord circuit.
Test plugs (with lineman's control circuit).

The wire-chief's desk is combined with a special card-catalogue desk containing the fault cards of the subscribers.

The satellite exchanges are equipped with the following desks:

1. The Vár exchange similar to the main exchanges.
2. The other satellites have each a combined desk, one position having equipment like that under (a), (b), (c), (e) above, but with suitable reduction.

Preparations Prior to the Introduction of Automatic Service

To facilitate the period of transition, the following was accomplished:

(1). Courses and lectures were held for the engineers, test and maintenance staff, for a year or so. As an example, Figure 5 was shown to explain the operation of the automatic system.

(2). Popular pamphlets were issued giving directions for the use of subscribers.

(3). Practical teaching in dialling on models of various types. Demonstrations were given in a comprehensible manner of the operation of an automatic exchange, as shown in Figure 6.

(4). Public lectures were given accompanied by moving pictures. Figure 7 is a reproduction of part of the film explaining how a connection is made.

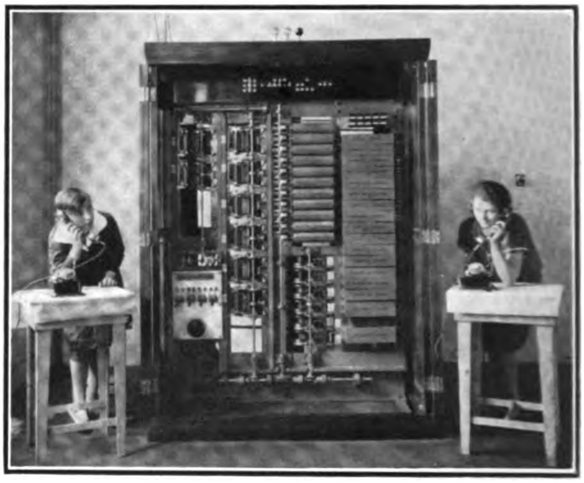


Figure 6—Model of Automatic Equipment Used for Demonstration Purposes.

Conclusion

The first stage of the installation of the automatic telephone exchanges in Budapest has been brought to a conclusion after nearly three years of preparation, manufacture and installation. The equipment was cut into service without the least trouble.

On April 28, 1928, 2,400 subscribers were connected to the Krisztina exchange, and their satellites; and on May 12 the number was increased to 2,600. On June 9, a total of 1,100 subscribers were connected to the Belváros exchange, that number having been increased by 5,000 on June 24. (The floor plan of the Belváros exchange is shown in Figure 8.) During July, the Teréz automatic exchange was cut-over with 9,400 subscribers. It will be evident, therefore, that in all there have been cut into service 20,000 automatic subscribers. The whole cut-over was made by the experts and personnel of the Hungarian Post-Office Administration, and of the Standard Electric R/T (Standard Villamossági Reszvény Társaság), Budapest, Hungary, the manufacturers of the equipment. On the 21st of July the manual Teréz exchange—which had been in service for nearly twenty-five years—was closed, and the Hungarian Post-Office Administration took leave of the old equipment and its personnel at an appropriate gathering (Figure 9).

It is gratifying to note that the transition period has been satisfactorily passed without any serious trouble, and also that the subscribers have taken to the automatic service with great pleasure.

The provision of progress lamps on the registers made it possible for any dialling errors of the subscribers to be followed at the beginning. By means of line jacks, it was possible to get in touch promptly with the subscribers and to draw their attention to such errors as were being made.

Instruction was accepted in a friendly manner. Subscribers of the manual exchanges are at present overwhelming the Administration with requests for automatic service. These wishes cannot for the time being be fulfilled. The installation of automatic exchanges will be continued until the end of the year 1931; the transition of the József manual exchange to full automatic service is not, however, to be expected before that time.

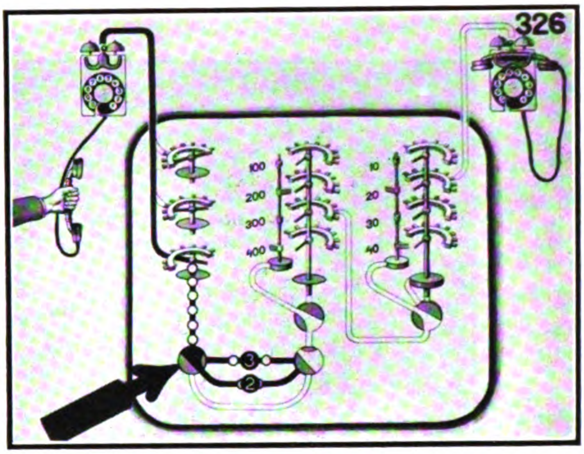


Figure 7—Illustration of the Cinema Film.

Calculations which were made in the years 1920 and 1921 have been fully verified. It is only in the Krisztina area, on account of an increase in building activity in this part of the town, that there has been an unforeseen increase in the number of subscribers that it will be necessary to consider in the further installation of the automatic exchange equipment. Therefore, the Krisztina exchange, in which case provision was made for extensions, will be equipped with 8,000 lines. The Lágymányos exchange will be equipped with 3,600 lines. On account of these developments it has been necessary to prepare plans for a 70,000 line instead of a 65,000 line area, and to modify the quantity of exchange equipment that will be required.

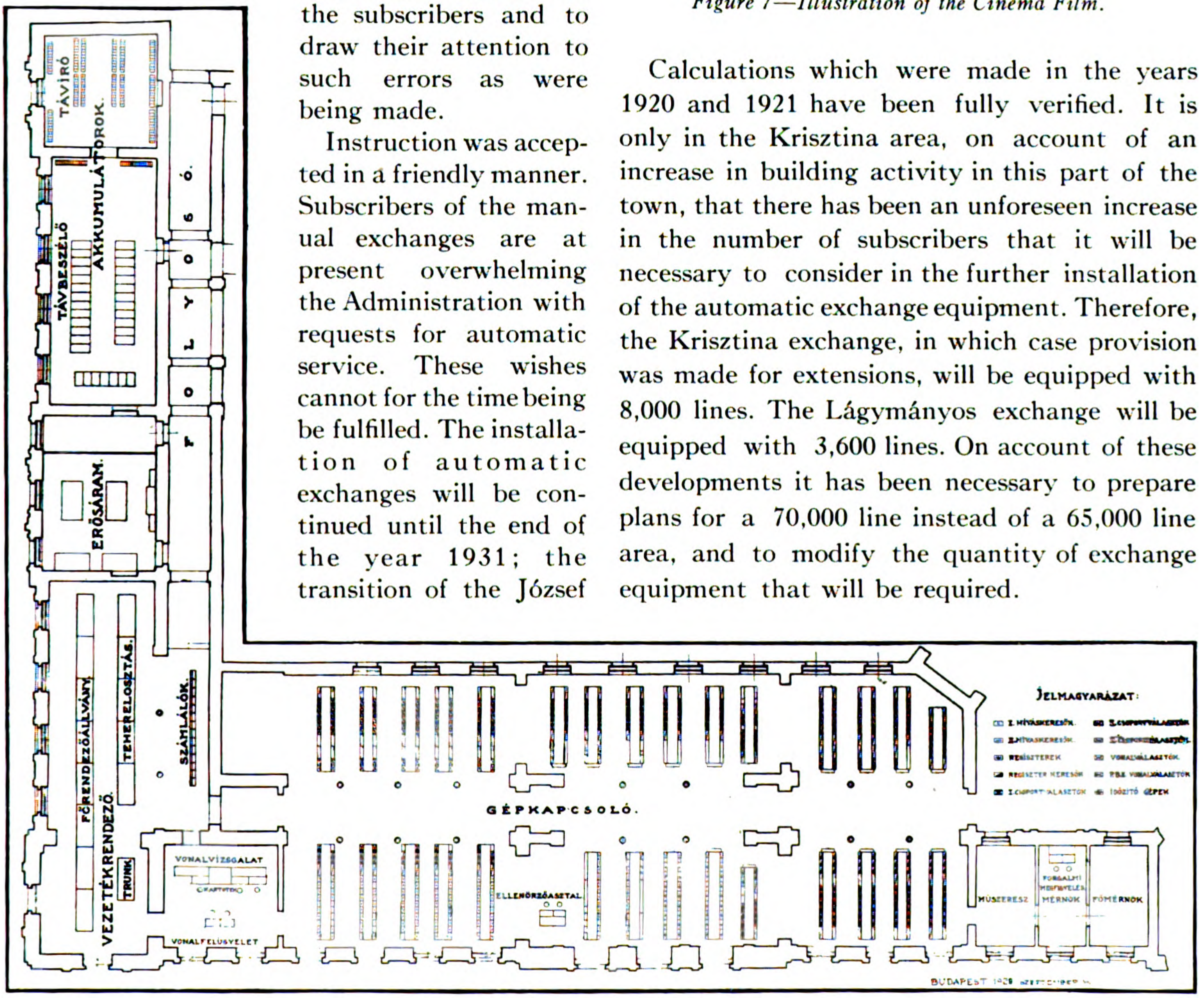


Figure 8—Floor Plan of the "Belváros" Exchange.

In veiw of the results which have been obtained, especially the small number of faults, it can be stated with assurance that these automatic exchanges—produced almost entirely by Hungarian manufacturers—will fufilll the expectations of the Budapest public.

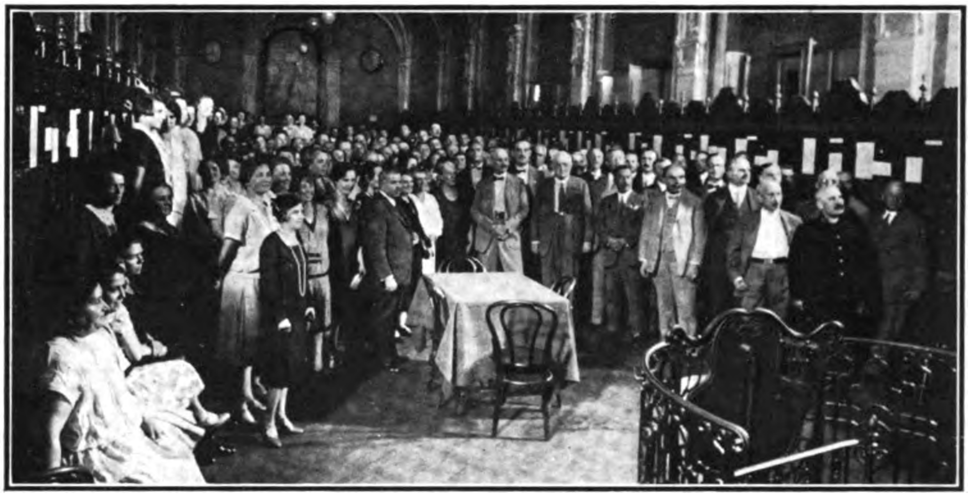


Figure 9—Last Evening in the Old Manual Teréz Exchange.

Handwörterbuch Des Elektrischen Fernmeldewesens

NOTWITHSTANDING the phenomenal growth of electrical communication in the last decade, there is a general lack of a comprehensive encyclopedia of terms used in the communication art. Two quarto volumes, HANDWÖRTERBUCH DES ELEKTRISCHEN FERNMELDEWESENS, edited by Dr. Ernst Feyerabend, Dr. Hugo Heidecker, and Professor Franz Breisig of the Reichspostministerium and Mr. August Kruckow, President of the Reichspostzentralamt, have been published in German recently by Julius Springer, Berlin. Not only have technical subjects such as theoretical electricity, telegraph, telephone and wireless technique, and the construction of lines and conduits been treated, but material of biographical, commercial, legal, and international interest also has been included. Undoubtedly the information contained in these volumes will prove highly useful to the engineer, the manufacturer and the industrialist as well as to the journalist and the statesman.

A New High Power Radio Broadcasting Equipment

By D. B. MIRK

Les Laboratoires Standard, International Standard Electric Corporation

THE trend of modern design in broadcasting transmitters is towards higher power stations with better quality transmission. Three main factors have contributed towards this movement:

(1) Broadcasting is now an everyday part of a nation's life, and as such must be regarded as one of the Public Services. It serves a large and fast increasing percentage of the population, and consequently the demand for "good quality, good strength" programmes is becoming more and more insistent.

(2) The limitation of wavelengths in the broadcast range to 84 exclusive wavelengths, and their allocation as agreed by the Union Internationale de Radiophonie, means that each European country is endeavouring to make the utmost of its exclusive wavelengths. The tendency is therefore to make the broadcasting stations operating on these wavelengths of as high power as is economically possible.

(3) The utility of a broadcasting station is largely determined by the extent of the area which it serves with "good quality, good strength" signals. Provided the area fed is more or less densely populated, as is usually the case in the neighbourhood of large towns, the increase in the power of the broadcasting station has the advantage of serving a greater number of listeners at a lower relative cost per unit.

Accordingly, to meet this demand, a High Power Broadcasting Equipment has been developed by the International Standard Electric Corporation. The equipment was manufactured by Standard Telephones & Cables, Ltd., and was erected and tested at their Works at New Southgate, London.

The latest broadcasting technique makes it possible to obtain up to 100 per cent linear modulation. The advantages of deep modulation are not generally understood, and it is thought that some explanation may not be out of place here.

Electrical disturbances are constantly present in the ether, and if these disturbances are of the same order of frequency as the carrier, the receiving equipment picks them up at the same time as the carrier. The disturbances beat with the carrier in much the same way as the side bands do, thus producing the audible noises familiar in all radio receivers. The noise is therefore proportional to the carrier, and consequently every effort should be made to increase the power in the side bands, as in this way the received signal strength may be increased without the attendant increase of noise which is more or less inevitable with increased carrier.

It is well known that for 100 per cent modulation the average or mean power is 1.5 times the carrier power, and that the power rises to a peak value of four times the carrier power.[1] This peak power is really the limiting factor in the rating of any broadcast transmitter. For 100 per cent modulation we must rate the unmodulated carrier power at one-fourth of the peak power which the transmitter is capable of handling, but if smaller percentages of modulation are required, then the carrier power can be correspondingly increased, provided the design is capable of dealing with the increased average power which will result from an increased carrier with smaller percentage modulation. Therefore, for a given peak power, it must be decided whether the transmitter should be designed for a large carrier with small percentage modulation or maximum percentage modulation and a smaller carrier. It can be shown that the lower carrier with maximum modulation gives the greater received signal. As stated above, the signal-to-noise ratio is also greater for the condition of maximum modulation. The equipment, therefore, has been designed for 100 per cent linear modulation. The estimated peak power available, corresponding to the highest point of the straight part of the load characteristic, is 180 K.W. Consequently, the antenna carrier power to permit of 100 per cent linear modulation was estimated at 45 K.W. Subsequently it was found on test that 100 per cent linear modulation could be obtained with a carrier power of 50 K.W.

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[1] R. A. Heising, Proceedings of the Institute of Radio Engineers, August, 1921.

The Design of Broadcasting Transmitters

It has been said that the governing feature from the point of view of public service is the provision of high quality reliable broadcasting with the minimum of interference. It may therefore seem reasonable to base the design of the broadcast transmitter on the public demand. This would mean that, since best present-day receiving sets are only responsive over a frequency range of approximately 50 to 5,000 cycles, a transmitter capable of successfully reproducing this band of frequencies would fulfill the requirements. However, since the technique of successful high quality reception is becoming more universally appreciated, both by listeners and manufacturers, the deficiencies of the receiving set will no doubt gradually be remedied, and consequently the broadcast transmitter should be designed to be capable of fulfilling the conditions which may possibly be required by the listener some years hence. It is generally agreed that the normal human ear cannot appreciate as music, frequencies below 30 or above 10,000 cycles. It is felt that a broadcast transmitter which is capable of reproducing this range of frequencies will meet all future requirements, and that this, therefore, should be the aim of modern design.

Broadcasting must also be regarded as a commercial enterprise, and in this respect economics naturally play an important part in the design of a transmitter. This means that the equipment must be efficient from the point of view of power consumption, simple to operate, and designed so that possible interruption due to fault or breakdown is reduced to a minimum.

Lastly, every possible precaution should be taken to prevent interference in any way with other broadcasting or commercial transmitters.

To meet these requirements then, a transmitter must be designed to have the following features:

(a) *High Quality Transmission.* Technically, this means that the input response curve of the transmitter must be sensibly linear over a range of audio frequencies from 30 to 10,000 cycles, and that the transmitter must be capable of 100 per cent linear or distortionless modulation. The radiated carrier should be free from any variation.

(b) *Power Supply.* One of the chief maintenance costs of a broadcasting transmitter is the power supply cost. Therefore every endeavour should be made to reduce to a minimum the actual power taken from the mains, without reducing the quality or reliability of the transmission.

(c) *Simplicity of Operation.* The operation of the transmitter should be simple and methodical, so that the staff requirements can be reduced to a minimum. Further, the transmitter should be easy to maintain, and in this respect, facilities should be provided for automatically removing any voltages which in the event of the occurence of a fault are likely to damage costly apparatus. Every precaution should be taken, and safety devices should be incorporated, to prevent the operators coming into contact with any dangerous voltage.

(d) *Continuity of Programme.* The possibility of faults should be reduced to a minimum, and facilities should be provided so that if a fault occurs, indication is given immediately to show the location of the fault. Further, audible and visible indication should be given to the staff immediately the transmitter ceases to operate properly. Where possible, the equipment should be designed so that it is capable, either by means of duplication or running at reduced power, of continuing its programme in the event of faults.

(e) *General.* The range of wavelength used for broadcasting is roughly from 300 to 600 metres. If possible, therefore, the transmitter should be designed to cover this wavelength band, and it should operate satisfactorily and efficiently over the complete range without recourse to elaborate changes in the tuned circuits. Short wavelengths are now being used extensively for commercial communication; and to prevent interference with these services, every effort must be made to reduce the strength of the radiated harmonics from the broadcast transmitter to the lowest possible value.

In the design of the high-power broadcasting transmitter described hereinafter, every endeavour has been made to meet these requirements.

Description of the Radio Broadcasting Equipment

The radio broadcasting equipment contains all the apparatus necessary to pick up the speech or music in the studio and deliver it in the form of modulated radio frequency currents to the antenna. It comprises essentially the speech input equipment, the radio transmitter, the power supply equipment, and the control apparatus. A block schematic of the complete equipment is shown in Figure 1.

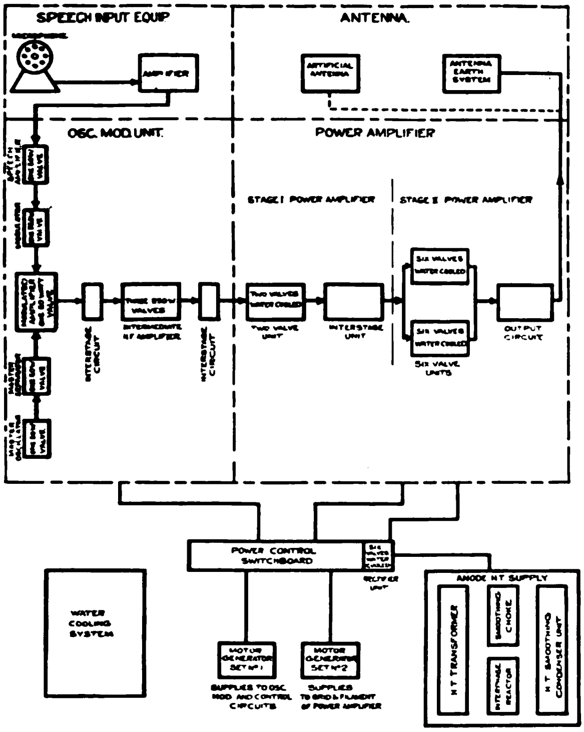

Figure 1—Block Schematic of Radio Broadcasting Equipment.

System of the Transmitter. The system used is one of modulation at low power, with subsequent high frequency amplification. The carrier power is generated in a low power master oscillator. The oscillator in this case does not synchronise its frequency with a higher power oscillator, but provides the sole drive for the equipment. The subsequent stages merely amplify the master oscillator output, and are designed so that they cannot in any way affect its operation. Modulation takes place at a slightly higher level than the master oscillator output, after which the modulated wave is amplified by three stages of high frequency amplification, the output from the last stage feeding the antenna. Provision is made to prevent frequency modulation with consequent distortion, as a result of any reaction on the master oscillator through valve capacity or otherwise, from the modulated amplifier or the power amplifiers. Figure 2 shows a simplified schematic of the transmitter.

The principles of efficient high frequency amplification are well known; [2] hence, only a brief reference to the operation of the amplifiers will be necessary. Generally, amplifiers may be described under two groups; those which forbid and those which allow the passage of grid current. The first group is the type generally used for audio frequency amplifiers where it is essential to operate on the straight part of the charac-

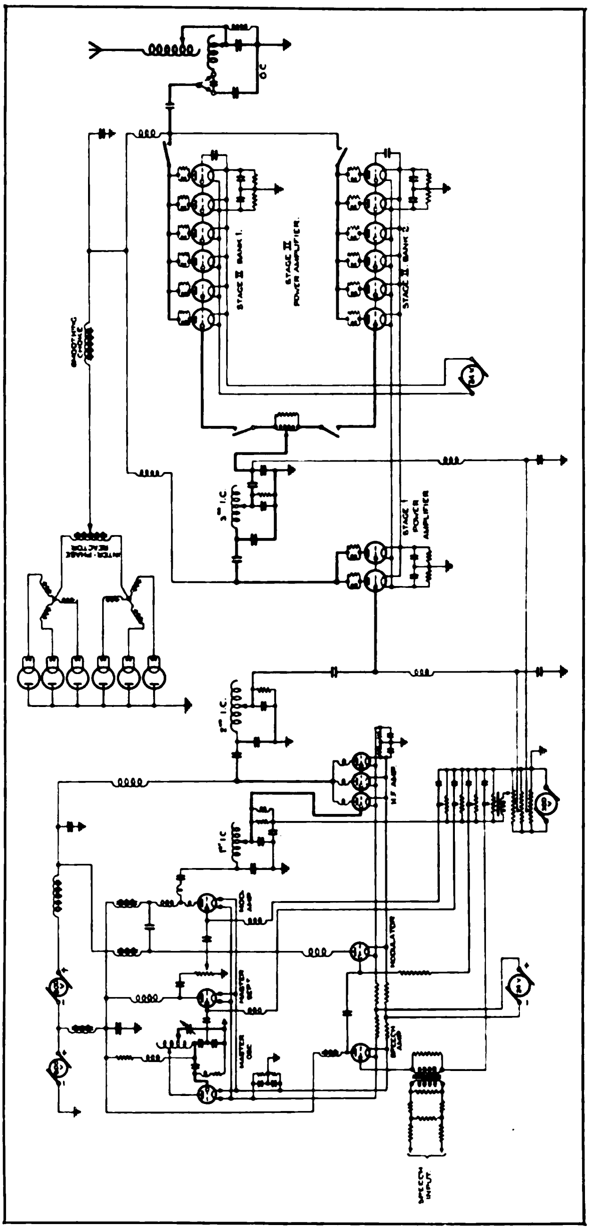

Figure 2—Simplified Schematic of the Radio Transmitter.

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[2] A. A. Oswald and J. C. Schelling, Proceedings of Institute of Radio Engineers, June, 1925.

teristic, and to limit the grid driving voltages to prevent the grid becoming positive. This type of amplifier has a very low efficiency. In the second group, used for high frequency amplifiers, grid current is permitted, and a much larger efficiency is obviously available with attendant production of distortion and harmonics. For audio frequency amplification, these harmonics cannot be eliminated, and consequently grid current is never permissible. With high frequency amplification, however, this method of operation results in the production of high frequency harmonics which are well separated from the fundamental or carrier wave. Hence, it is comparatively easy, by the use of suitably designed interstage and output circuits, to eliminate them, and to prevent their radiation from the transmitting antenna. The value of the grid polarising potential is therefore selected at or near the point of anode current cut-off, and the grids are driven with large alternating potentials. During each radio cycle, the grid swings positive to such an extent that appreciable grid current flows.

Circuit Design. The system of modulation adopted is equivalent to that devised by Heising, commonly known as "Choke Control." A 50 watt valve, which is designated the "modulated amplifier," and which works as a high frequency amplifier, is modulated by a 250 watt modulator valve. The anode feed current to this valve passes through an audio frequency choke, the voltage across this choke being varied at audio frequency by the modulator valve. The design is such that for 100 per cent linear modulation, and with a constant high frequency grid drive, the output current of the modulated amplifier varies linearly with the anode voltage from zero to twice the normal operating anode voltage. The modulator valve is capable, without any departure from the linear characteristic, of varying the anode voltage of the modulated amplifier valve from zero to twice its normal direct current operating voltage. As the mean power output of the modulating system is raised by 50 per cent, for 100 per cent modulation, the modulator valve must be capable of supplying power equal to half the input power to the modulated amplifier. These requirements are met by the use of a 250 watt modulator valve. This valve is fed through a low frequency modulation choke from a 1,600 volt direct current supply, and the modulated amplifier valve is fed through another choke from an 800 volt direct current supply. The chokes are connected through a 10 microfarad condenser.

Considering now the circuits of the high frequency amplifiers, all the interstage circuits, and the output circuit, represented as I.C., and O.C., respectively, in Figure 2, are of the same type of parallel tuned resonant circuit. The function of these circuits is to receive the energy from the anodes of the valves of one stage and to deliver it at the correct level to the grids of the valves of the next stage, or to the antenna. The design must be such that the interstage circuit meets the output impedance requirements of the valves of the one stage, and the input impedance requirements of the valves of the next stage or of the antenna. The interstage and output circuits may be described as consisting of two legs, one leg having a capacity, and the other having an inductance and capacity in series (see Figure 3). The driving voltage for the grids is taken across the coupling condenser C.2 in the second leg. As explained previously, the large driving voltage applied to the grids of the high frequency amplifier causes the grids to become alternately highly positive and highly negative, the former condition resulting in the passage of considerable grid current. This method of operation results in a considerable variation of the grid filament impedance. This variation tends to be reacted back through the grid coupling condenser and the interstage circuit, thus affecting the anode circuit of the previous stage. To prevent this reaction, the grid circuit is heavily damped by a resistance of much lower value than

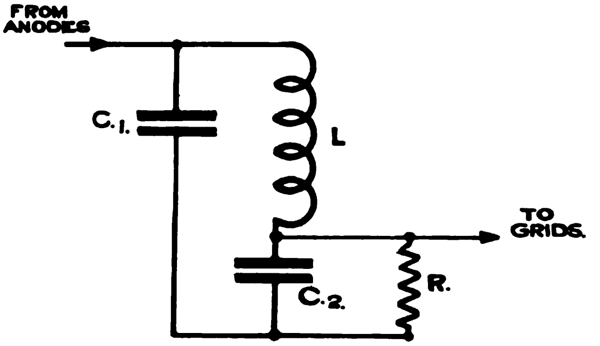

Figure 3—Type of Interstage Circuit used in the Radio Transmitter.

the minimum value of grid filament impedance. It is inserted across the grid coupling condenser, thus reducing to a minimum the effect of the variation of the grid filament impedance on the previous circuit. Owing to the fact that the reactance of a condenser is inversely proportional to the frequency, C_1 and C_2, both present a low reactance to currents at harmonic frequencies. This type of interstage circuit and output circuit has therefore exceedingly good harmonic eliminating qualities.

Three stages of high frequency amplification are employed: the first stage has three 250 watt radiation cooled valves, the second stage two 15 K.W. water cooled valves, and the third stage twelve 15 K.W. water cooled valves.

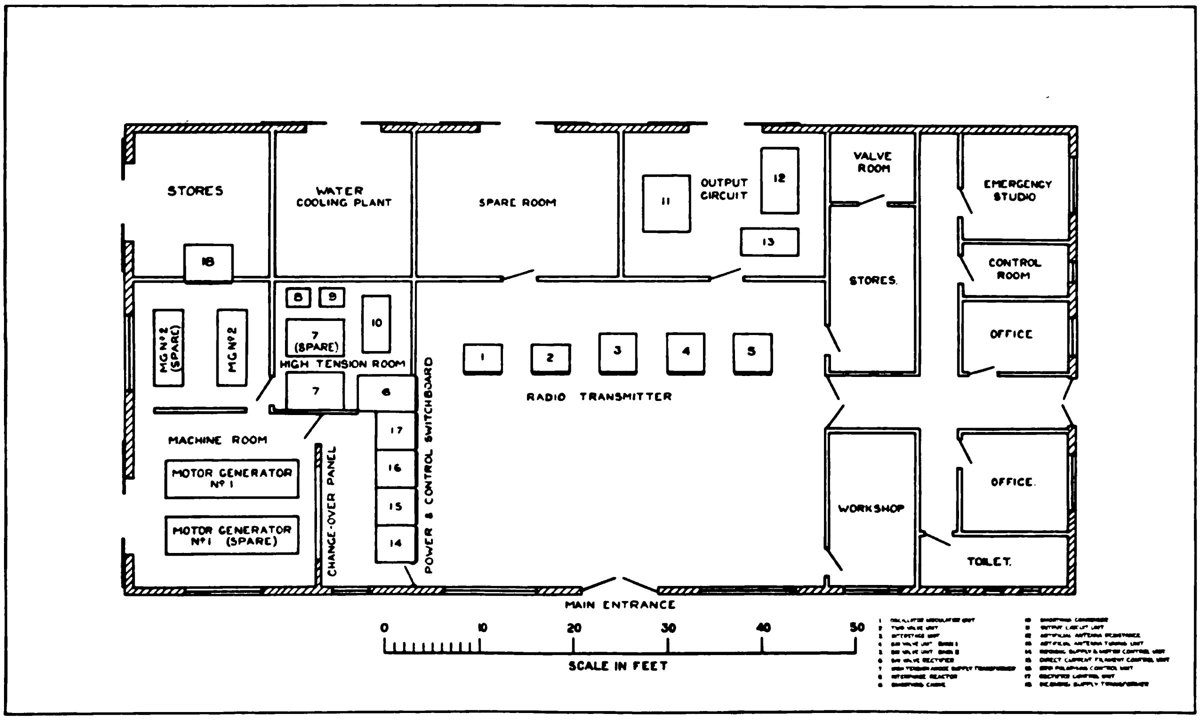

Figure 4—A Suggested Layout for the Equipment.

Layout and Arrangement. The layout of a broadcasting station of this power is so much dependent on the space available, the situation and location of the station, and the facilities required at the station, that it is not possible to specify any rigorous arrangement. Figures 4 and 5, however, are intended to indicate the type of layouts which would be suitable, and to show the floor space required for their respective arrangements.

The radio units of the Broadcasting Equipment are designed as isolated free-standing units, each unit being completely enclosed; they are arranged in line, with about 2 feet 6 inches separation between units. The power panels are built into a Power and Control Switchboard which faces, or is adjacent to, the radio units. The high tension enclosure containing the high tension transformer and filter unit, which forms part of the 12,000 volt direct current supply equipment, is located behind the rectifier unit, which is part of the power and control switchboard. Another enclosure is mounted behind the radio units containing the output circuit and the artificial antenna. With this type of layout it is possible to isolate all the running machinery from the radio transmitter. Furthermore, since the rectifier equipment for the 12,000 volt direct current anode supply, comprising the rectifier unit, high tension transformer, smoothing choke, condensers, etc., is located in one enclosure, the lengths of all connecting leads are reduced to a minimum, thus avoiding high frequency pick-up with the possibility of consequent carrier noise.

All the cables for the various power circuits are

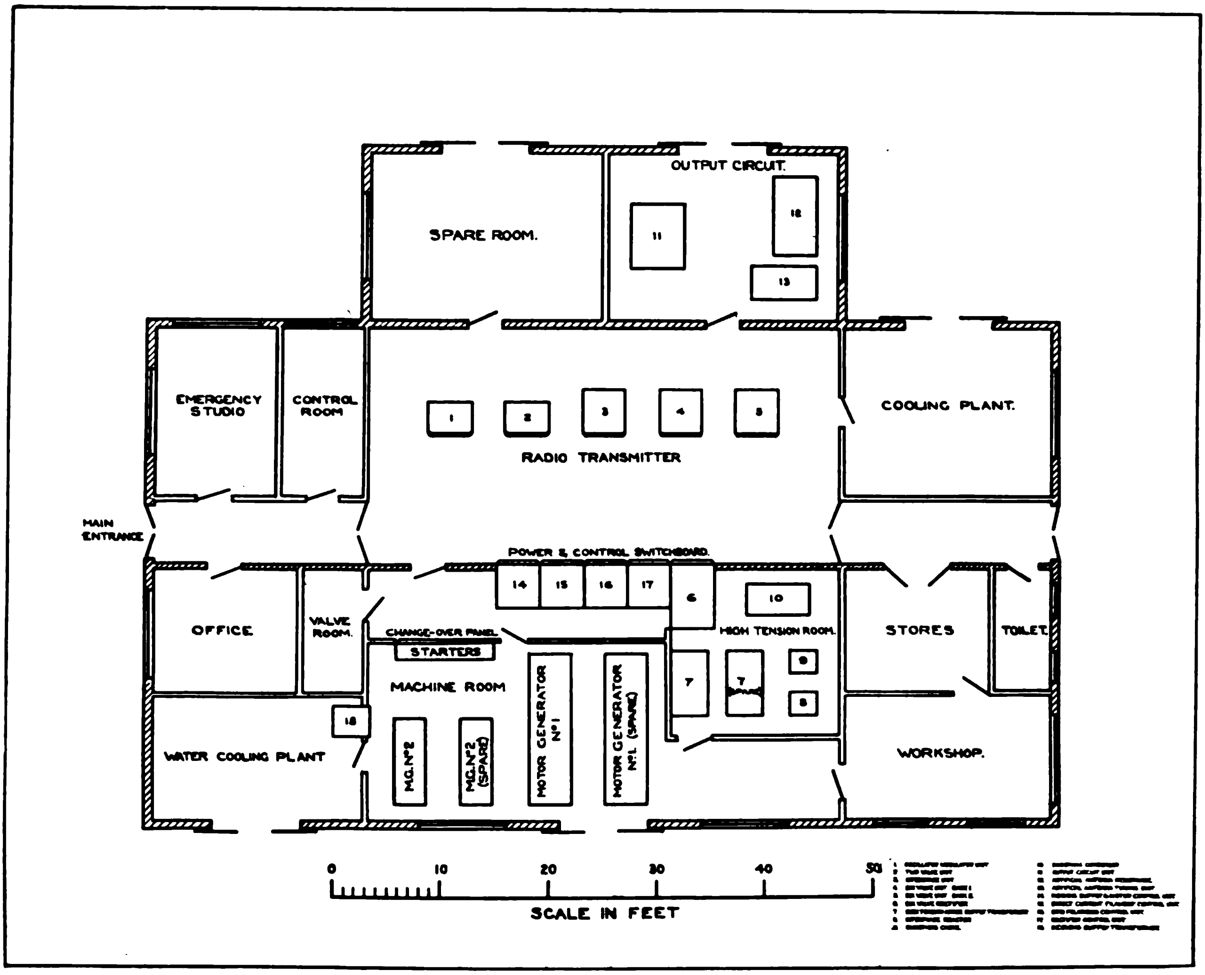

Figure 5—An Alternative Suggested Layout for the Equipment.

lead covered, and are run in trenches in the floor. The only bus bars visible are the high frequency connections between the radio units, and from the radio units to the output circuits. All these high frequency bus bars are run overhead in the form of transmission lines of concentric copper tubes, the outer one being earthed.

The main idea governing the station layout has been to consider the radio equipment quite apart from the power equipment. Hence all the machines and apparatus connected with power supply are located together and isolated as much as possible from the radio units. At the same time full consideration has been given to the necessity of easy operation, and consequently the power boards are arranged so that the operator attending to the radio units is also able to control all the power apparatus.

Speech Input Equipment. The function of the speech input equipment is to pick up the speech or music in the studio, transform it into electrical energy, amplify this energy to a suitable level for application to the radio transmitter, and provide facilities for controlling this level and for checking the quality.

The speech or music is picked up in the studio by a condenser microphone, which, with its associated amplifier, is mounted on a pedestal. The audio frequency currents from the condenser microphone equipment are passed through a three-stage low frequency amplifier before application to the radio transmitter. This amplifier, with the necessary controls, measuring and indicating instruments, together with the radio receiver and monitoring arrangements, is assembled in the control desk (Figure 6). This desk is located in the control room, and it is so arranged that all the controls are within easy reach of an operator sitting centrally in front of the desk.

The apparatus is mounted on steel panels assembled in three sections. The top panel in the left-hand section is the volume indicator panel. This is intended to assist the operator in controlling the amplification of the speech input amplifier in such a way as to keep within proper limits the wide variation in volume of the speech currents delivered to the radio transmitter. If this control were not exercised, the extremely wide change of energy produced by the sounds in the studio would cause the transmitter to be frequently overloaded, while at other times the transmitter would be almost inaudible. The indication of the volume level is given by a sensitive meter in the plate circuit of a valve which, for the convenience of the operator, is mounted on a gain control panel located in the centre section of the desk. Immediately below the volume control panel is a panel which carries the meters whereby the various filament and anode currents can be measured. Below the meter panel is the signal and control panel. A series of jacks is provided on this panel to give facilities for connecting up the appropriate lines for local or outside broadcasting.

Communication between the studio and the control room is obtained by means of local telephones, attention being attracted by a buzzer mounted on the signal and control panel and operated by a key located at some convenient point in the studio. A lamp is provided in the studio in place of a buzzer, to avoid disturbing the programme.

While the whole of the speech input equipment is designed to reproduce all frequencies uniformly, the characteristic of most receivers and loud speakers is usually far from straight. The deficiency is as a rule particularly noticeable on the lower frequencies. It is therefore generally desirable, under present conditions, to modify the characteristic of the speech input equipment, so as to emphasise the frequency components between 1,000 and 30 cycles. A special equalizer, located on the bottom panel of the left-hand section, has accordingly been provided, which effects this modification while leaving the characteristic practically unaltered from 1,000 cycles upwards. The advisability of its use or otherwise can only be determined by actual experience; hence, a key is provided on the panel which enables it to be cut in or out at will.

The top panel in the centre section of the desk is the amplifier panel containing three stages of low frequency amplification. The circuits are designed to give an exceptionally good characteristic with freedom from distortion. Potentiometers for controlling the gain are mounted on a separate gain control panel located below the amplifier panel. The potentiometers enable the gain of the equipment to be varied with maximum flexibility in small uniform steps; the operation of the potentiometers is noiseless.

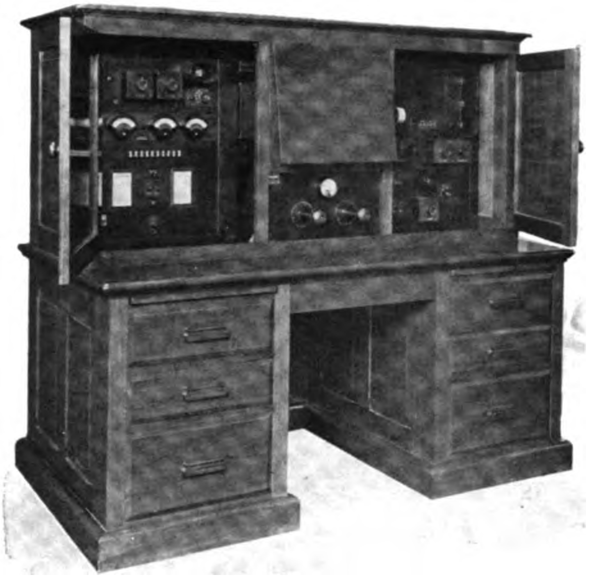

Figure 6—The Speech Input Equipment.

The top panel in the right-hand section is the receiving panel, comprising a detector and two stages of low frequency amplification. Below the receiving panel is mounted the monitoring amplifier panel which consists of one stage of amplification designed to work from the speech amplifier into a "Kone" loud speaker. In addition to observing the volume level it is desirable for the operator to maintain a constant check on the quality of the speech currents delivered to the radio transmitter, in order that he may detect any distortion due to overloading of the speech amplifier, and also observe any faults arising in the studio. At the same time, it is necessary for him to listen to the output of the radio transmitter, so that by making a rapid comparison of the input and the output, he may detect any distortion occurring in the radio transmitter proper. Experience has shown that continuous listening with a telephone head-set is inconvenient to the operator, and after a time causes him to lose the necessary fine discrimination of tone. The "Kone" loud speaker is therefore used for monitoring, either from the amplifier panel, or from the radio receiver panel, so that a rapid comparison may be made between the outputs of the speech input equipment, and of the radio transmitter.

Radio Transmitter. Figure 7 represents the radio transmitter, the five units, starting from the left, being the Oscillator Modulator Unit, the Stage I Power Amplifier Unit, the Interstage Unit, and the two Stage II Power Amplifier Units. From the point of view of accessibility and maintenance, the free-standing isolated unit type of equipment has very marked advantages for a broadcast transmitter of this power. Each unit is completely enclosed, access to the apparatus being gained through doors or gates in which safety switches are incorporated. It is impossible to have any high voltage on the unit unless these doors are closed; consequently, adequate protection is provided for the operators. The front panels are of polished black slate.

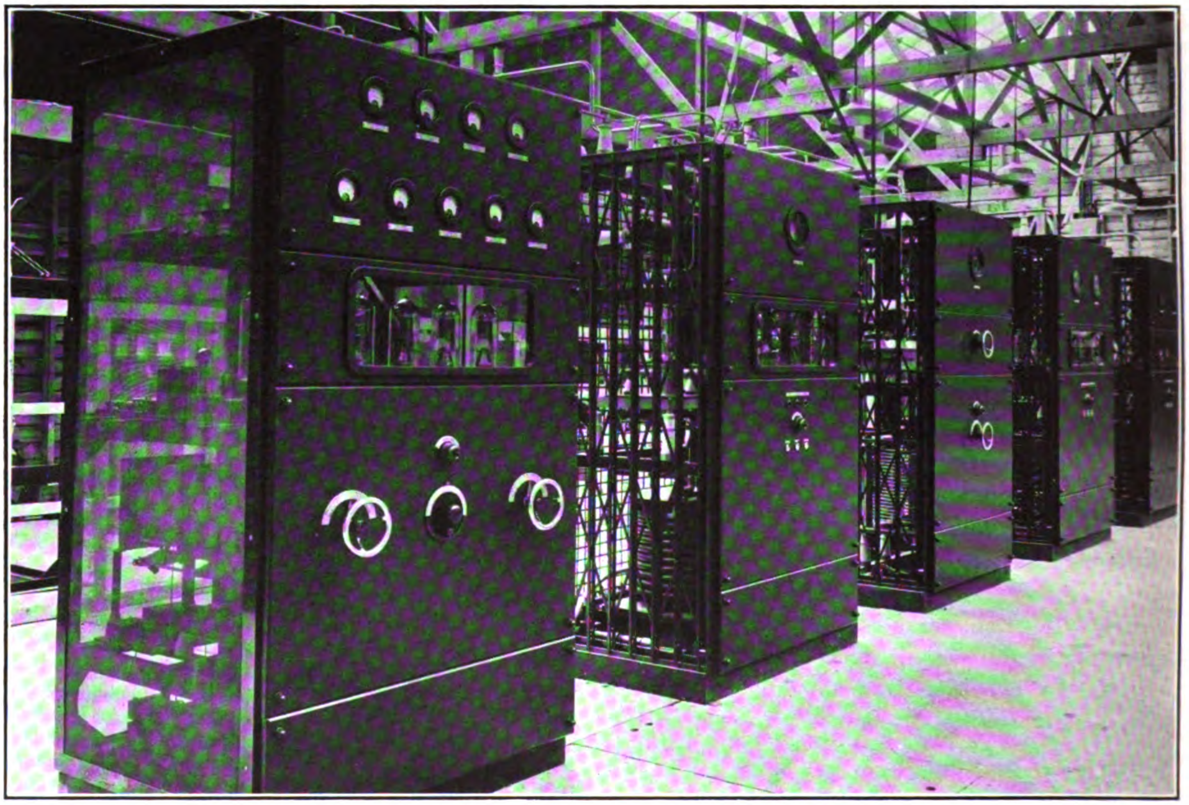

Figure 7—The Radio Transmitter Units.

The Oscillator Modulator Unit contains all the apparatus necessary for (a) the generation of the high frequency carrier at low power; (b) the modulation of the high frequency carrier by the audio frequency currents received from the speech input equipment; and (c) the amplification of the modulated energy to the requisite power level for application to the grid of the Stage I Power Amplifier.

The radio frequency carrier wave is generated at a low power level by a quartz crystal-controlled master oscillator. To obtain the maximum frequency stability possible, the temperature of the box containing the master oscillator is maintained constant by the use of a sensitive thermostat. In addition, the box containing the master oscillator is completely shielded from external fields. A coupling stage is inserted after the master oscillator, to prevent the master oscillator being affected by any variations in the load taken by the modulated amplifier during modulation. This coupling stage, designated the "Master Separator," is a 50-watt valve worked very lightly. Its purpose is to present a constant impedance to the output of the master oscillator. Allowing for as much as 10 per cent variation in each of the anode and filament voltages, the change of frequency will be less than 10 cycles. Further, neither temperature variation, nor even change of valves will cause the frequency change to exceed 10 cycles. The crystal-control may be switched out, and the oscillator used in a self-excited circuit if desired. The design is such as to give very good frequency stability even when used as a self-excited oscillator.

The 250-watt modulator valve is fed by a 50-watt speech amplifier valve, the circuits being so designed that virtually perfect reproduction is obtained over the complete audio frequency band. The modulated amplifier which receives its high frequency feed from the master separator through a resistance potentiometer, employs one 50-watt valve arranged to be modulated in accordance with the output of the modulator. An intermediate high frequency amplifier, consisting of three 250-watt valves, arranged in parallel, raises the level of the energy to that required for application to the grids of the Stage I Power Amplifier. Special precautions are taken throughout the Oscillator Modulator Unit to ensure that the carrier wave is entirely free from ripple. Smoothing systems are incorporated in the anode, grid, and filament supplies of all valves. The unit is completely shielded from any external interference.

The power amplifier comprises the remaining four units and the output circuit. Two stages of power amplification are necessary to increase the level of the output from the oscillator modulator to the level necessary for feeding the antenna. Fourteen water cooled valves are used, each capable of delivering 15 K.W. at 12,000 volts. The cooling water is fed to the anodes through rubber hose coils which provide a sufficient length of water path to reduce the leakage current to earth to a small value. Each water cooled valve is provided with an anti-singing device which is designed to prevent any possibility of intervalve oscillation.

Stage I Power Amplifier has two valves arranged in parallel, and Stage II consists of two units, each containing six valves in parallel. Stage II receives its drive from Stage I through the medium of the interstage unit. Normally the two Stage II units are operated in parallel, but by a simple switching arrangement it is possible to use only one six-valve unit, the antenna power being consequently halved. The switching is so arranged that the unit which is not in use is absolutely isolated from all voltages; thus, in the event of any fault occurring in the Stage II Power Amplifier, it is possible to isolate the bank concerned, and to run on the other bank while making necessary adjustments or replacements without causing any serious break in the programme. Figures 8, 9 and 10 are side views of the Stage I Amplifier, the Interstate Unit and one unit of the Stage II Amplifier, respectively.

The two units of Stage II are fed through a specially designed anti-singing network. This device is so arranged that it presents a low impedance to the feed currents from Stage I, but presents a high impedance to any parasitic oscillations which might be set up between the two six-valve units.

The output circuit is mounted in a framework, Figure 11, and is housed in an enclosure behind the radio units, the enclosure being fitted with safety gates. The tuning and aerial coupling condensers are connected to their respective bus bars through links which can be readily removed to obtain the correct condenser value for a given wavelength. The tuning condenser is arranged in two parts working in conjunction with a switch. By throwing over the switch it is possible to double the impedance of the output circuit, and so to present the correct impedance to the Stage II Amplifier when only one bank of valves is used.

The tuning of the interstage circuit is accomplished by adjusting the inductances through hand-wheels on the front of the oscillator modulator and interstage units. The output circuit is finally tuned by varying the inductance by means of a handle projecting through the output circuit enclosure.

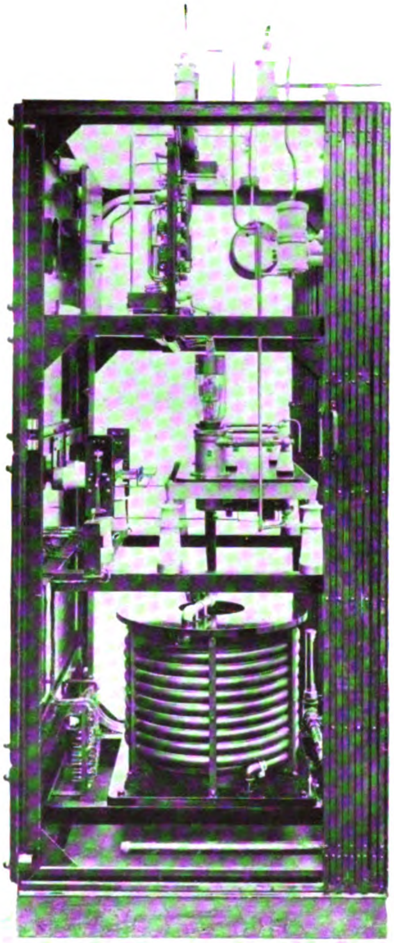

Figure 8—Side View of the Stage I Amplifier Unit.

Full protection has been provided for valves and other equipment of a costly nature, but at the same time, great consideration has been attached to the importance of producing an equipment with every facility for continuous running without interruption. With this end in view, every means has been provided for giving a quick and clear indication of the location and cause of any fault which may occur, so that any possible trouble may be rectified with the utmost ease. All the valves in the unit are protected against anode current overload by relays in the anode circuits. In the power amplifier, which uses water cooled valves, a separate relay is associated with each valve; in the event of an overload, these relays remove the anode voltage from the valves. The water cooled valves are protected against failure of the water supply by a special water flow alarm which removes the filament, grid, and anode voltages from the valves in the event of a failure of the water flow. Provision is also made against excessive cooling water temperature, a thermometer being supplied which removes the filament, grid and anode voltages from the valves when the temperature of the water exceeds a safe value.

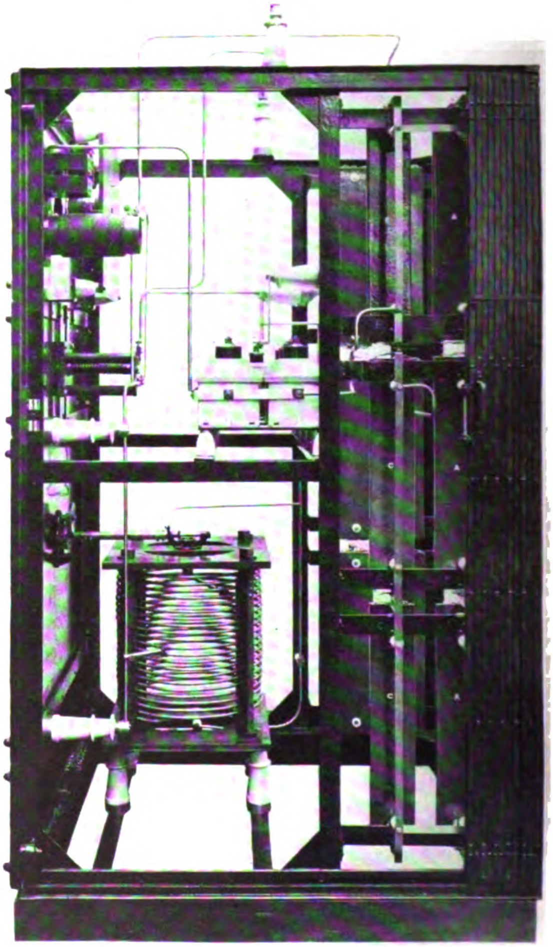

Figure 9—Side View of the Interstage Unit.

Spark gaps are provided throughout the equipment, which break down in the event of any excessive voltage, and remove the anode voltages from the valves.

Power Supplies

The equipment is designed to operate from a 415-volt 3-phase 50-cycle incoming supply.

The valves used in the Oscillator Modulator Unit are radiation cooled valves operating at anode potential of 800 and 1,600 volts. Machines are used for supplying the filaments, grids and anodes of the oscillator modulator valves. All the power amplifier valves are water cooled, and they derive their filament and grid supply from machines also, but their anode supply of 12,000 volts is obtained from a High Tension Thermionic Rectifier Equipment.

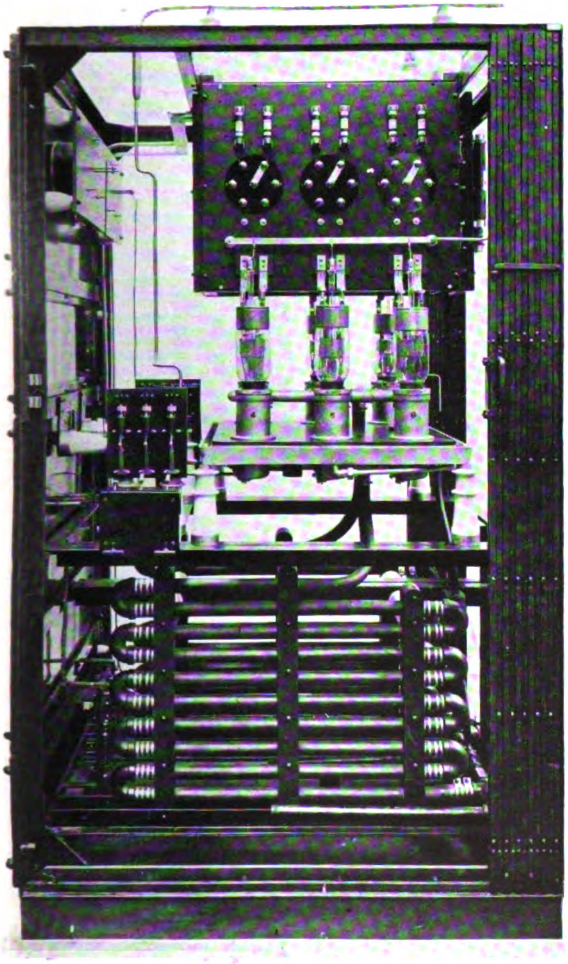

Figure 10—Side View of a Stage II Amplifier Unit.

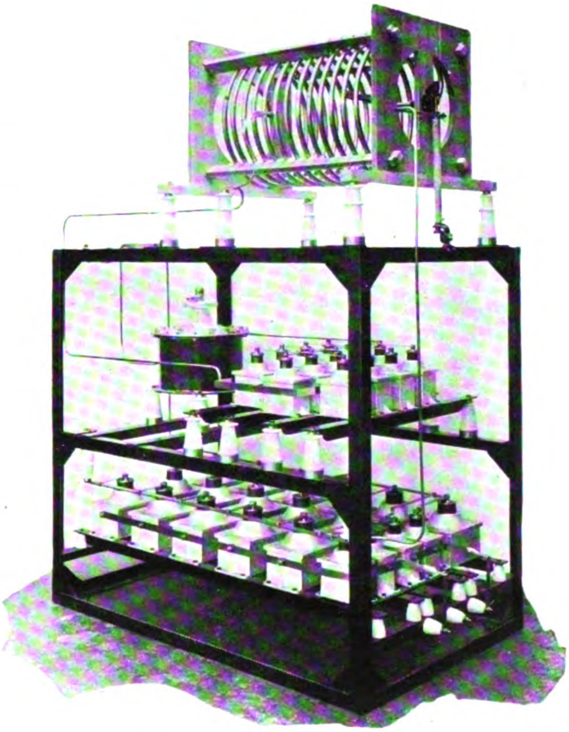

Figure 11—The Output Circuit.

Motor Generators. Two motor generator sets are used. Set No. 1 has two generators directly coupled to a squirrel cage induction motor. One generator has a double commutator and gives direct current outputs at 800 and 1,600 volts for supplying the anodes of the valves in the Oscillator Modulator Unit. The second generator gives a 24-volt direct current supply for the filaments of the oscillator modulator valves, and in addition supplies the power for the various control circuits.

Set No. 2 has two generators directly coupled to a squirrel cage induction motor. One generator supplies the filaments of the power amplifier valves with direct current at 24 volts; the other generator provides the grid bias voltage for all the valves used in the equipment.

These motor generator sets are specially designed so that the ripple of the generator is very small. In addition, however, filter circuits are incorporated in all the supplies to reduce the ripple further, and thus to ensure that the carrier wave is entirely free from noise.

12,000 volts D.C. Anode Supply. The total direct current required for feeding the anodes of the water cooled valves of the power amplifier is of the order of 14 amperes. This is obtained by transforming the alternating supply to the necessary voltage and rectifying it with a thermionic valve rectifier; then, by means of a properly designed filter circuit, the harmonics in the rectified wave are reduced so that the percentage ripple remaining in the direct current supply is negligibly small. As the transmitter is designed for a three-phase supply, it is evident that the best conditions for the reduction of ripple would be obtained by adopting a system using a polyphase rectifier. Each phase of the rectifier, however, necessitates the use of one valve. For an equipment of this size, economic considerations limit the number of valves used to six. With a six-phase rectifier, each valve theoretically passes current for one-sixth of a cycle, whereas with a three-phase rectifier the current flows for one-third of a cycle. From this point of view, the six-phase rectifier is less efficient than the three-phase rectifier. However, the advantages of both six-phase and three-phase rectification may be realised by using a "three-phase double star" rectifier system. This type of rectifier has therefore been adopted; the scheme of connections is shown in Figure 1. The system consists essentially of two three-phase rectifiers connected in parallel, with the transformer arranged so that the two secondary stars have a phase difference of 180°. The total current through each rectifier must be kept constant in order that each may act as a true three-phase rectifier. This result can be accomplished by fitting a choke in the output of each rectifier and, more economically, by the use of one choke connected between the two star points, the rectified output being taken from the centre point of this choke. The direct currents in the two halves of the choke oppose each other, thus producing no resultant flux in the choke. The function of this choke, which is called the interphase reactor, is to prevent large ripple currents flowing round the circuit consisting of the two three-phase rectifiers in series, the main smoothing choke preventing large ripple currents flowing through the two rectifiers in parallel and the load.

Only those ripple frequencies which are even multiples of the supply frequency appear in the potential wave at the mid-point of the reactor. Those frequencies which are odd multiples of the supply frequency have opposite phases in the two halves of the rectifier, and consequently cancel out. Therefore, with a three-phase 50-cycle supply, the lowest frequency present in the rectified wave is 300 cycles, and its voltage amplitude is only 5.7 per cent of the direct current voltage. The 150-cycle ripple, which is present in the simple three-phase rectifier system to the extent of a voltage amplitude of 25 per cent of the direct current voltage, is thus eliminated.

The three-phase double star system, therefore, gives the same percentage ripple in the rectified supply as the six-phase rectifier, while it is as efficient as the three-phase rectifier, in that each valve passes current for one-third of a cycle.

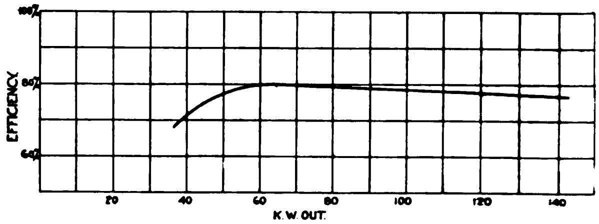

Figure 12—Efficiency Curve of the H. T. Thermionic Rectifier Equipment.

Figure 12 shows a measured efficiency of 77 per cent for an output of 14 amperes at 12,000 volts direct current, the efficiency being measured as a ratio of the direct current output of the rectifier to the power input to the high tension transformer, plus the power dissipated in the rectifier filaments.

The rectifier consists of a High Tension Transformer, Interphase Reactor and Induction Regulator, a Rectifier Unit and a Filter Unit. The transformer is provided with switches and tappings on the primary, to give a direct current voltage variation on the anodes from 4,800 to 12,000 volts in ten steps, and an induction regulator is supplied to vary the voltage between any two of these steps. It is therefore possible to obtain a continuously variable voltage from 4,800 to 12,000 volts. The incorporation of these

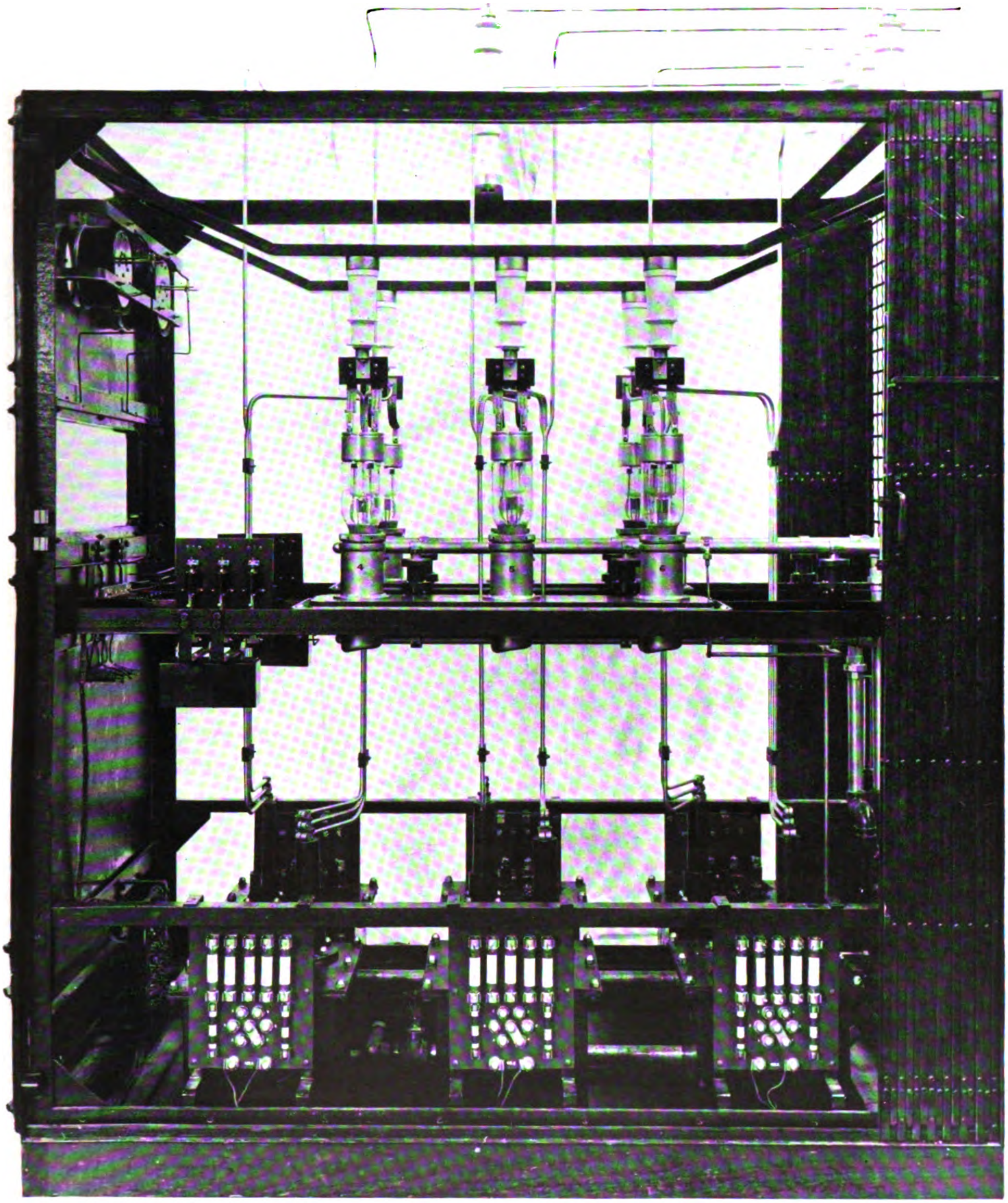

Figure 13—Side View of the Rectifier Unit.

switches and the induction regulator, together with the facilities for running either one or two "6-valve units" enables a very flexible output to be obtained from the transmitter. Furthermore, the fine control of the anode voltage by the induction regulator enables the output of the station to be kept absolutely constant during the entire broadcast programme.

The six water-cooled valves, together with six filament transformers and the associated apparatus, are assembled in the Rectifier Unit shown in Figure 13. In the case of a high power rectifier using water-cooled valves, it simplifies design to connect the anode of the rectifier to earth, thus obviating the necessity of supplying hose coils for insulating the anodes. Each valve has a separate filament transformer which is highly insulated, the filaments being at high potential for both alternating and direct current, the primary of the transformers being connected to the 415-volt incoming supply. The valves are protected against current overload, excessive cooling water temperature, and the failure of water flow, in the same manner as the 15 K.W. water-cooled amplifier valves.

The filter unit consists of an oil-immersed choke coil and a high tension smoothing condenser, so designed to reduce the ripple in the 12,000 volts direct current supply to less than 0.1 per cent. A smoothing condenser of 15 microfarads capacity is supplied. This large value is used, not only for its effect in reducing the ripple, but also to present a low impedance to the audio frequency currents supplied to the amplifiers during modulation. This low impedance prevents the 12,000-volt anode supply from varying, and thus from causing remodulation and consequent distortion.

Power and Control Switchboard. The Power and Control Switchboard consists of four polished black slate panels, which, together with the Rectifier Unit, are assembled in line, side by side, Figure 14. The panels are arranged so that the station is started up by successive operations moving from the first to the fourth panel. At the rear of each panel the associated switchgear and control apparatus is assembled in an iron framework. The Power and Control Switchboard with the Rectifier Unit presents the appearance of one complete unit, nineteen feet four inches long and six feet six inches high. The control of all the power circuits of the equipment and all the normal switching operations and adjustments are carried out here. The direct current for the filaments can be easily controlled by the generator field rheostats, thus enabling the valves to be slowly warmed up before the anode voltage is applied. In the same way, a three-phase resistance enables control to be obtained of the alternating current for the filaments of the rectifier valves.

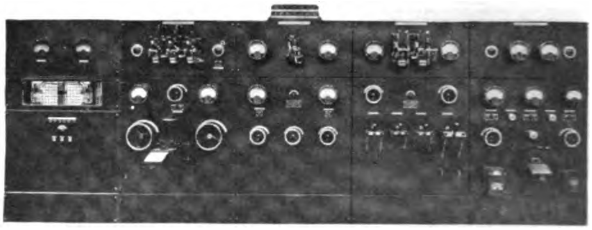

Figure 14—Front View of the Power and Control Switchboard.

All the control and protective relays are mounted on a relay rack, or central control panel, in an accessible position on the framework at the back of the switchboard, so that in the event of any trouble in the control or protective circuits, the fault can be located immediately by simple tests. The front view of the relay rack with the relay covers removed is shown in Figure 15. The main function of the apparatus mounted on this rack is to ensure that the filament, grid, and anode supplies are applied in the correct sequence, and to remove the voltages concerned in the event of any fault occurring. Briefly, the action of the control and protective circuit is to remove the high tension voltage in the event of the failure of the filament or grid voltage or of the operation of any of the gates, emergency, or overload devices. It also serves to remove the grid voltage in the event of the failure of the filament voltage; and to remove the filament voltage if the flow of water fails or is insufficient, if the temperature becomes excessive, or if the main supply of water fails.

Located at the top of the switchboard is a bank of indicating lamps, having a name plate designating the purpose of each lamp. Should any of the above failures occur, a lamp is lit, thus showing the location and nature of the fault immediately. It is impossible to apply power again as long as any of the lamps remain alight, that is, until the fault is cleared.

An electric clock gives a direct reading of the number of hours the filament and anode of each valve have been working.

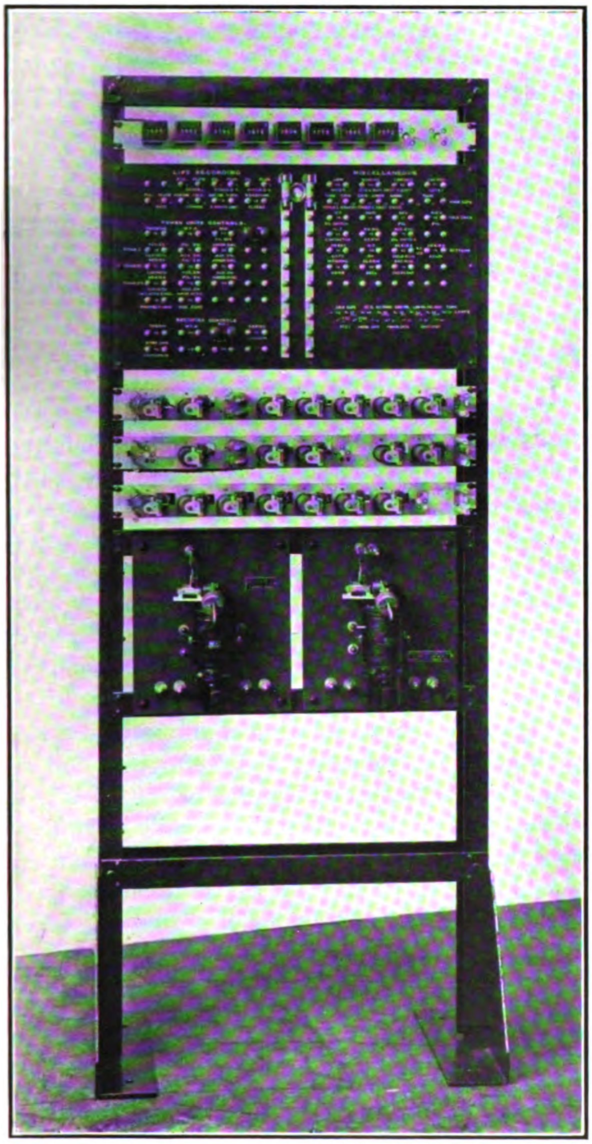

Figure 15—Relay Rack, Front View.

The Power and Control Switchboard is built into a wall, so that all the live switchgear is situated in a room behind the switchboard panels, access to which is obtained through a safety gate.

Water Cooling System. Provision is made for a water supply of two gallons per minute for each water-cooled valve, that is, a total supply of 40 gallons per minute, or 2,400 gallons per hour. The efficient cooling of such a quantity of water is a problem in itself, and may be approached from many angles, depending on the local conditions. It is advisable, in order to prevent scaling of the anodes, to use either distilled or rain water, and as the cost of the former is high, and a supply of the latter in some countries is inadequate, the cooling system adopted should be as efficient as possible, and not one where losses may occur due to evaporation.

For the testing and operation of the transmitter at New Southgate, London, where there was a plentiful supply of cooling water, the cooling system installed consisted of a water circulating system comprising a motor-driven pump, an elevated tank on a tower structure, a tank at ground level, a filter, and a pipe run. The elevated tank has a capacity of 600 gallons, and the ground tank a capacity of 5,000 gallons. Water is drawn from the ground tank by means of the pump, and is fed to the elevated tank, about 40 feet above the ground. When the equipment is running, water flows by gravity from the elevated tank through the valves, and returns to the ground tank through which the heated water has to circulate before being re-used. A float apparatus fitted with two floats is contained in the top tank. When the water in the top tank falls to a certain value the topmost float causes two contacts to be closed, which start up the pump motor. The pump motor continues to run until the water in the top tank has risen to the correct level. The second, or lower float is arranged so that when the water falls below a certain level, two contacts are opened which cause the station to shut down. Thus, in the event of any serious failure in the water supply, sufficient water is left in the tank when the station is closed to circulate round the valves and to allow the anodes to cool. This system operates very successfully. It has the disadvantage, however, of having a large area tank exposed to the atmosphere, and in a location where the air is not too pure, extraneous matter may find its way into the water, and either cause a stoppage of the flow at the filters, or probably cause deposit on the anodes. Furthermore, the proper working of the system is dependent on the radiation of heat from the surface of the tank, and in warmer countries this may not be sufficient. Another suitable system using a double water circuit is therefore suggested. In this system the primary water supply to be cooled circulates through brass tubes, around the outside of which cold water is circulated from the secondary water supply. The secondary water supply may be a cooling pond or tank or a natural lake or river, if such is in the vicinity. With this system only a comparatively small quantity of pure water, either distilled or rain water, is required. The secondary cooling water need not be of any special purity. Two pumps are provided, one to circulate the water round the primary circuit and the other to circulate the water through the secondary circuit.

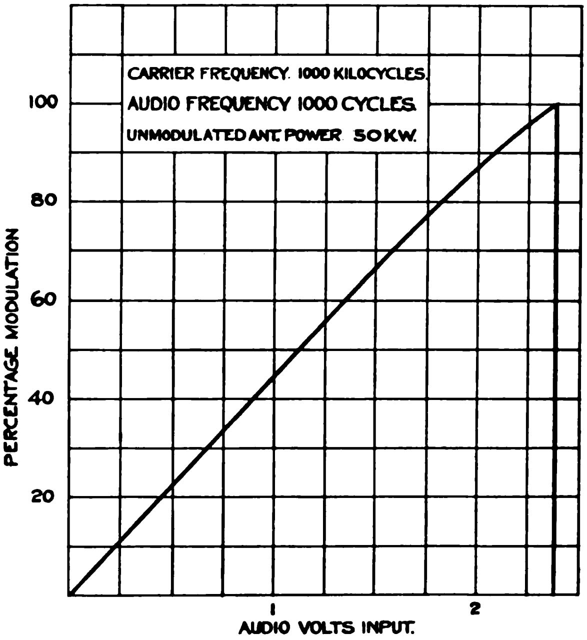

Figure 16—Overall Modulation Characteristic.

Monitoring Equipment. As it is essential that the operators should be able to judge the quality of the broadcast transmission, a monitor is incorporated. This is tapped across a part of the output circuit, and consists of a 50-watt valve arranged as a diode rectifier, its output being a non-inductive resistance, across part of which is connected a "Kone" loud speaker. The monitoring equipment is designed to have a characteristic which is practically linear from 30 to 10.000 cycles.

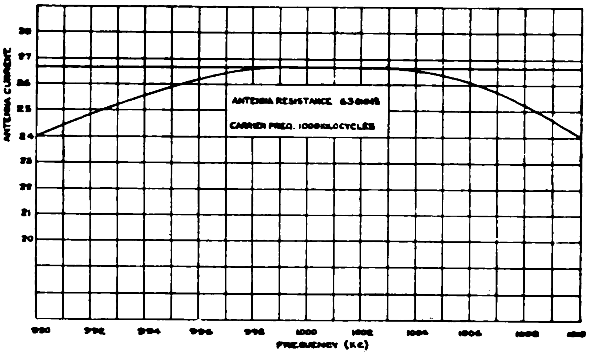

Figure 17—Overall Band-width Characteristic of the Radio Transmitter.

Performance of the Radio Transmitter

To avoid interfering with the reception of the London Broadcast Programmes, it was found necessary to make most of the tests on the transmitter with an artificial antenna. This consists of a variable inductance, a variable capacity, and a variable non-inductive resistance load, capable of dissipating 75 K.W. of energy, this representing the completely modulated power corresponding to 50 K.W. telephone carrier power.

Figure 16 is a modulation characteristic taken with an audio frequency of 1,000 cycles, and an unmodulated antenna power of 50 K.W. It shows that the transmitter is capable of 100 per cent linear modulation. The ideal transmitter would give this curve for all audio frequencies between 30 and 10,000 cycles; that is, for a constant audio input, the antenna output should be constant for all frequencies between 30 and 10,000 cycles. This necessitates, first, that the high frequency circuits should be designed so

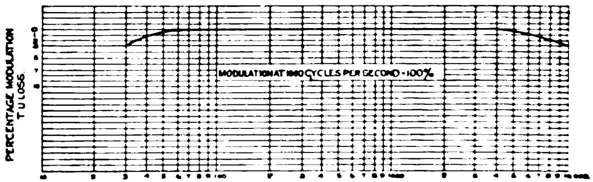

Figure 18—Overall Frequency Characteristic of the Radio Transmitter.

that they are capable of responding equally to all frequencies from 10,000 cycles below the carrier frequency to 10,000 cycles above. Figure 17 shows that the response or band-width of the transmitter, though not linear, does not depart from linearity sufficiently to be noticed. Secondly, it is necessary that both the low frequency and high frequency circuits should be capable of equal response for all frequencies from 30 to 10,000 cycles. Figure 18 is the overall characteristic of the radio transmitter over this band of audio frequencies for a constant audio input corresponding to 100 per cent modulation at 1,000 cycles. It shows that the divergence from linearity is so small that it could not be detected by the most sensitive ear.

The overall efficiency, that is, the ratio of antenna power to total power taken by the station from the mains, is about 20 per cent. This efficiency is considered exceedingly good for a high quality broadcasting equipment of this power.

It is well known that the operation of a number of valves in parallel is a likely cause of trouble. In the design of the equipment, therefore, every endeavour was made to reduce this tendency to a minimum. In this respect it has been pointed out that devices were incorporated to prevent intervalve oscillation, or oscillation between the two banks of valves in the last stage. Furthermore, it was anticipated that some trouble might be occasioned from what is familiarly known as "Rocky Point" effect, which results in a very heavy anode overload in the valve. Considerable precautions were taken, therefore, in the way of individual valve overload relays, etc., to prevent much damage being done in the event of this occurrence. Not the slightest evidence of "Rocky Point" effect has been given during the testing of the transmitter. The transmitter proved to be perfectly stable, and gave a consistently excellent performance over a wavelength range of 280 to 600 metres. Interruptions in the continuity of a programme can only be caused by absolutely abnormal circumstances, such as any other power plant might encounter.

It may be stated that the performance of the transmitter shows it to fulfill all the herein mentioned requirements.

A Solution of the Problem of the Broadcasting Microphone

By A. H. REEVES

Les Laboratoires Standard, International Standard Electric Corporation, Paris

SINCE the inception of broadcasting six or seven years ago, the microphone has always been the weakest point in the radio transmitter, just as the loud speaker has always been the weakest link in the receiving apparatus. So difficult has been the problem that there has not heretofore been available a single microphone capable of meeting simultaneously the demands of quietness, uniform efficiency at all useful frequencies, and linearity of response. Where a measure of success has been obtained in one direction, it has always been at the expense of a requirement in some other direction, and too often the apparatus has been inconsistent and unreliable in its performance.

Recent development work of the International Standard Electric Corporation has produced a reliable pick-up device free from spurious noise, capable of reproducing uniformly a frequency range from 30–10,000 periods per second, and having perfect linearity of response to all amplitudes which are capable of being handled by the amplifying valves employed. Extreme quietness has been made possible by the combination of a special high frequency circuit with a novel balancing arrangement for eliminating noise in the high frequency generator. The net result is an improvement in noise energy ratio of twenty-five times over the best known earlier type of equipment.

The condenser transmitter has always been known to be singularly free from distortion, and a number of different types have been used at different times, both in circuits using steady polarising voltages, and in high frequency circuits.

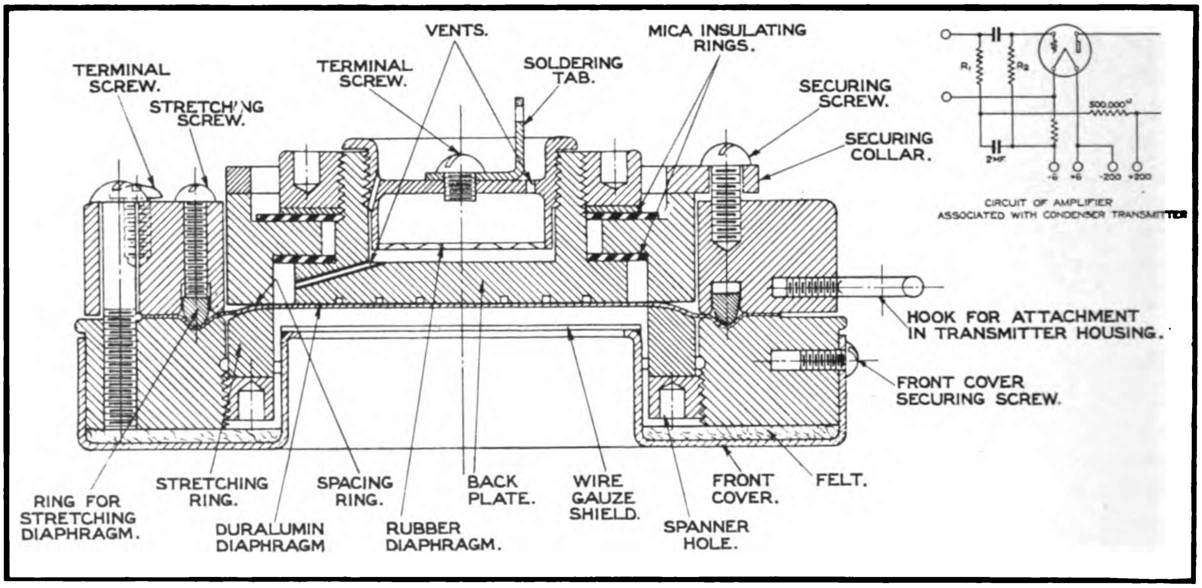

Figure 1—Section of MS. 1670 Condenser Transmitter and Circuit of Early Amplifier.

The first tendency in developing the condenser transmitter used by the International Standard Electric Corporation was towards the production of a reliable instrument passing a wide range of frequency. This development, carried out by Wente in the United States, resulted in the production of a highly reliable and robust piece of apparatus passing a frequency range from 30 to above 10,000 cycles per second. A section of the MS. 1670 Condenser Transmitter developed by Wente is shown in Figure 1, together with the circuit in which it was normally employed. This instrument, used with a steady biasing potential in the above circuit, suffered from the disadvantage that its efficiency was so low that the thermal agitation, in the resistances feeding it, was sufficient to cause appreciable background noise. A source of further noise was the presence of moisture or dust introducing leakage paths in parallel with the high resistance associated with the amplifier input; and maintenance of amplifiers in a condition of minimum noise was therefore difficult. In spite of these difficulties, condenser transmitters of this type were successfully used in a number of studios, notably at WEAF in New York, Birmingham, Zurich and Prague. Wherever it was used, the fidelity of this instrument, due to its wide frequency range and freedom from asymmetry, was recognised to be unsurpassed. A typical frequency response characteristic for one of these instruments as used previously (in the circuit of Figure 1) is shown in Figure 2. Deviations from this characteristic in manufacture are relatively small, a remarkably homogeneous product resulting. The increase in efficiency of this instrument at the base served to compensate for the shortcomings common to all early apparatus; it is not so certain that such a characteristic would now have advantage over a flat characteristic, and for this reason in developing the new equipment a flat characteristic has been aimed at.

Owing to the difficulties of maintaining an amplifier free from noise, the MS. 1670 condenser transmitter, as the next step in development, was abandoned for one passing a narrower frequency range, but having an increased sensitivity. A characteristic of one of these instruments, the ES. 619 condenser transmitter, is shown in Figure 3.

The new equipment has been developed by reverting to the MS. 1670 transmitter and employing a new type of circuit to eliminate noise.

Referring to Figure 1, in the earlier circuit used changes of capacity between the diaphragm and the back plate resulting from sound waves impinging on the diaphragm, cause fluctuations of voltage across the transmitter itself—the charge on the condenser transmitter from the 200 volt battery being maintained substantially constant due to the high value of the time constant of the circuit formed by the condenser transmitter and the resistance effectively in series with it. These fluctuations are applied directly to the grid of the first valve of a low frequency amplifier. The capacity of the transmitter being about 300 micro-microfarads, the leakage resistances R_1 and R_2, in order to avoid distortion and reduction in sensitivity, must have values of the order of at least 15 megohms, which means that a very high degree of insulation is necessary in order to avoid noise caused by irregular leakage. If precautionary measures are not taken, the leakage noise may easily mask the irreducible noise caused by the e.m.f. of thermal agitation in the resistances R_1 and R_2.[1] Under the conditions mentioned, the latter results in a noise equivalent to approximately 5 R.M.S. microvolts applied between the grid and filament of the first amplifier tube and is, with good tubes and components, the most important factor in noise production.

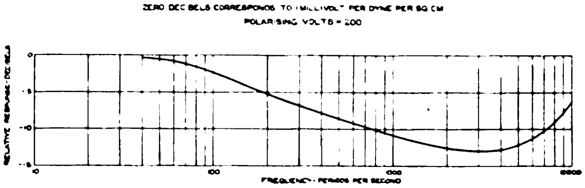

Figure 2—Characteristic of MS. 1670 Condenser Transmitter.

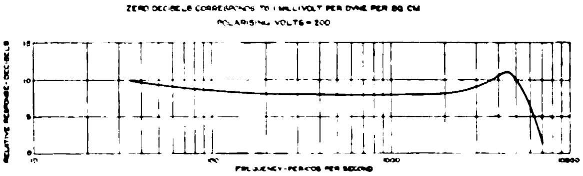

Figure 3—Characteristic of ES. 619 Condenser Transmitter.

The outline of the new circuit is shown in Figure 4. The essential principle involved is the utilisation of the changes in capacity of the transmitter to alter the tuning of an inductance-capacity circuit coupled to a radio frequency oscillator. The condenser transmitter is used as a tuning condenser across a small inductance; an oscillator of fixed frequency, high as compared with the highest audible frequencies to be considered, is coupled weakly to this tuned circuit. The constants are adjusted until the condenser transmitter circuit is not exactly in tune with the oscillator; the working point on the resonance curve in practice is at X, Figure 5. When sound waves arrive at the diaphragm of the transmitter, the capacity of the latter changes, and the tuning point is correspondingly altered, thus changing the amplitude of the high frequency voltage across the transmitter. It is evident that there is now, in effect, a carrier frequency modulated by the arriving sound wave, exactly as is the outgoing wave of a broadcasting station. It only remains to rectify the high frequency voltage, after which output at speech frequency will result.

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[1] J. B. Johnson, "Thermal Agitation of Electricity in Conductors," *Physical Review*, July, 1928.

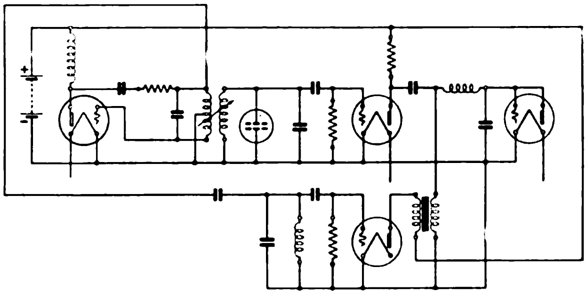

Figure 4—Circuit of High Frequency Equipment Associated With Condenser Transmitter.

It will be seen that the working point X, Figure 5, is approximately at the steepest part of the resonance curve and not at its apex—an adjustment which gives comparatively large changes in high frequency amplitude for small changes in capacity. In this way a sensitivity to the arriving sound wave is provided, which is considerably in excess of that obtained by the earlier method of Figure 1. In addition to this considerable advantage, there are others which, in fact, surpass the first in importance. One of these is that the very high resistances previously required, are now unnecessary. It would be possible to operate the new circuit without using any leaks at all; this scheme, however, would not be very convenient in practice, as a grid bias battery of a high and very constant voltage would be necessary on the rectifier tube. To avoid this, a grid leak of one megohm is used with a blocking condenser in series with the H.F. input, causing the grid current itself automatically to give the optimum grid bias. Since the resistances are only one megohm in value, and of wire-wound construction, they are perfectly reliable.

The second advantage is the fact that the original high impedance to audio frequencies between grid and filament is now eliminated. By reference to Figure 4, it will be evident that this impedance is now quite low, the reactance of both the series blocking condenser and the tuning inductance at frequencies between 35 and 10,000 cycles being less than 5,000 ohms. This fact considerably reduces noise voltage at audio frequency due either to external pick-up, to slight variations in the apparatus components on the input side of the rectifier, or to thermal agitation. Even at the carrier frequency and the frequency of the resulting side bands, the impedance is considerably less than fifteen megohms, being in fact under fifty thousand ohms.

An occasional source of a large amount of tube noise is also practically eliminated by this means; viz., the component of the rectifier tube noise due to leakage between the plate and grid. In practice, however, there would be no excuse for employing a valve having a defect of such comparatively rare occurrence.

The net result of the above circuit changes is an improvement in speech-noise ratio over the circuit of Figure 1 of at least 14 decibels; and it is possible to obtain a further appreciable reduction varying between 6 and 10 decibels, because the bulk of the residual noise is contributed by the oscillator, and this can be considerably reduced by means of a special balancing circuit. The oscillator valve noise modulates the high frequency at its source, thus giving rise to audio

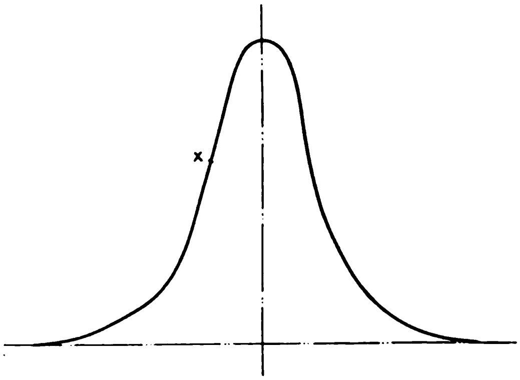

Figure 5—Resonance Curve.

frequency noise after rectification. The output from the oscillator is supplied to a subsidiary rectifier, across the input of which is an inductance-capacity circuit similar to that across the input of the main rectifier which contains the condenser transmitter. The second circuit is also approximately tuned, with a clamped variable condenser, to the oscillator frequency, and coupled to the oscillator circuit sufficiently to receive the necessary voltage across its terminals. The output of the subsidiary rectifier, therefore, contains the same noise in its output circuit as does that of the main rectifier, but unlike the latter, it has no music or speech in its output. The output from the two rectifiers are combined in opposition by means of a transformer, so that any modulated tones in the oscillator output itself arrive in opposite phase from the two oscillators, and are therefore balanced out. The speech, which affects only the input of the main rectifier, remains unchanged. The total improvement over the circuit of Figure 1 is therefore between 20 and 24 decibels.

The method of obtaining grid bias will now be considered in further detail. The normal peak value of high frequency voltage on the grid is of the order of 45; a mean negative grid bias of this order, therefore, is required on both rectifier tubes, to avoid overloading. Such a bias could be obtained by means of a separate grid battery, but this would necessitate very accurate regulation of voltage. An accidental 10% variation, for example, would give a change of 4½ volts on the grid, which would probably put the apparatus out of operation altogether.

The method used eliminates this difficulty. The high frequency voltage is applied to the rectifier grids through two series condensers, each of the order of one microfarad; grid-filament leaks of one megohm each are added. Assuming that the grid voltages start from the zero value, when the first positive half-cycle arrives on the grids, large grid currents immediately flow, giving the grids a negative charge. This effect will be increased by each subsequent positive impulse, as the escape of charge by means of the grid leaks, the latter being of high value, is much slower than the rate of charge by grid current. The mean grid bias will continue to become more negative until its value is only slightly less than the peak voltage of the input high frequency e.m.f. This action, giving approximately the best bias value for working conditions, will take place regardless of the value of high frequency input voltage.

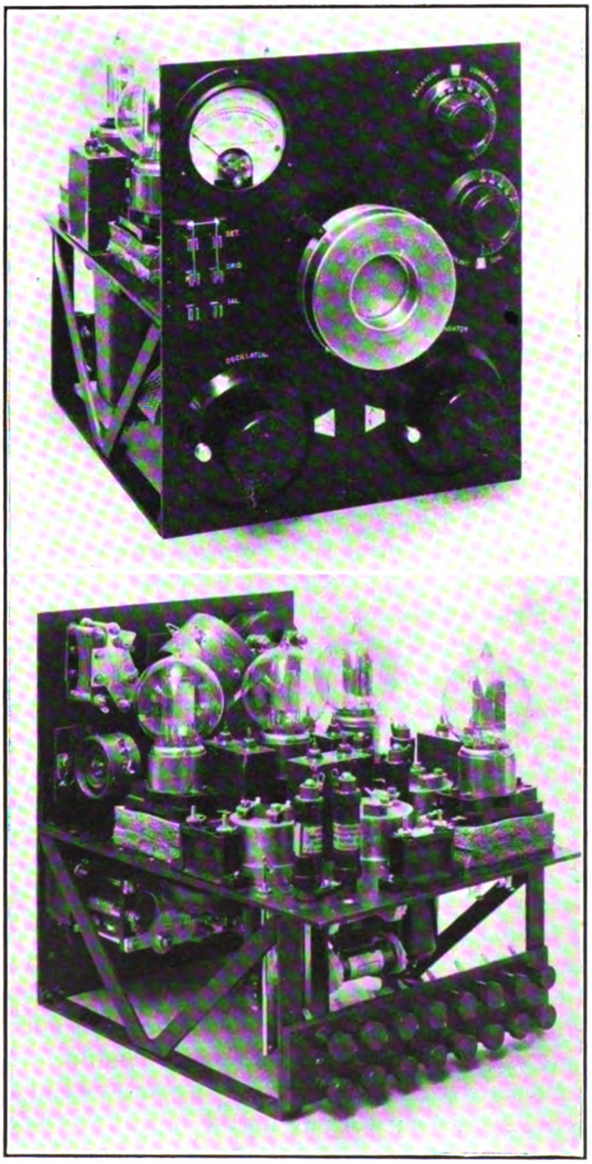

Figure 6—Condenser Transmitter Recently Developed by the International Standard Electric Corporation.

A further advantage of the new circuit is the fact that the normal peak voltage across the transmitter is only 45, whereas 220 is the usual value for the old circuit. This greatly reduces risk of trouble due to the breakdown of the condenser transmitter itself.

The two chief advantages of the condenser transmitter already mentioned, namely, good quality, and the absence of "blasting," are maintained in the high frequency equipment.

The particular apparatus developed by the International Standard Electric Corporation according to the above design is shown in Figure 6. This form, intended for studio work only, contains the transmitter and the amplifier mounted together in one unit. A single flexible screened cable supplies the necessary D.C. power to the apparatus, and also contains the low frequency output leads. The dimensions of the box are 13¾ x 10¼ x 11¼ inches. The power input of the present model requires 6 volts at 5 amperes, 150 volts at 70 milliamperes, and 25 volts (grid bias) at 10 milliamperes, the negative low tension and the positive grid bias leads being common. The box and the leads are screened to avoid external pick-up noises.

Several difficulties of theoretical interest were encountered during the development work. It may be thought on first consideration that an oscillator frequency of about the same value as that ordinarily employed in "carrier" work would be suitable for the present apparatus. This is not the case, however, if attenuation of the high audio frequencies is to be avoided. Calculation shows that the effects of operation, not at the apex of the resonance curve, but at a point on its steep part, in general causes the two side bands to be out of phase with each other. This phase inequality increases up to a certain point as the audio frequency increases, and so causes the audio frequency currents, due to each side band separately after rectification, to be to some extent in opposition. This effect increases attenuation at the high audible frequencies to a point greatly in excess of that obtained when working at the top of the resonance curve. In order to meet this difficulty, and at the same to maintain a resonance sharp enough to give good sensitivity, a carrier frequency of the order of 600 kilocycles has to be used. With this value, and with the circuit adjustments finally employed, the extra attenuation due to the high frequency circuits at 10,000 cycles is less than 2 decibles.

The second point of interest is the effect of any variable contacts in the neighbourhood of the high frequency circuits, whether connected to these circuits or not. Any such contact is liable either to form a closed loop, thus obtaining e.m.f. from the oscillator by magnetic induction, or to pick up high frequency voltage by capacity coupling. In either case, when the contact changes, there is produced a reactive effect on the circuit itself, owing to the change in absorption in energy from it, causing a crack or a splutter in the output of the low frequency stages. To overcome this source of trouble it has been found necessary for every metal part, even though small, either to be connected definitely to some part of the circuit, or to be thoroughly insulated from it. Even a component, such as a screw fixing the handle of the box, if allowed to make variable contact with the handle, has at times been found to be a source of noise. Nevertheless, when once the necessary precautions were taken, no further trouble was experienced.

A further difficulty presented itself when the other noises had been reduced to a low level. The source was found to be variable contacts between the filaments and the filament hooks in the tubes themselves, particularly in the case of the oscillator tube. Just before the completion of the present development work this defect of many of the present tubes had been realised and overcome by a new method of construction, the remedy applied by the International Standard Electric Corporation being to weld the filaments directly to the hooks. After some slight difficulties, owing to the sag of the filament under these new conditions, had been overcome, the new tubes were found to be quite satisfactory.

Metal bases were found unsuitable for the tubes used in this apparatus on account of their sudden expansion during the process of heating up, causing "cracks" in the output circuit; bakelite bases were found to be free from this defect and are now used throughout. A similar effect and also a cause of occasional noises, was traced to the sudden expansion of several of the components during the heating resulting from switching on the batteries. The mechanical vibrations produced in this way caused the tube elements, and also the inductances and variable condensers to vibrate, again giving objectionable noises. The remedy used in this case, up to the present time has been to use anti-microphonic sockets for the tubes, and to support together every component sensitive to vibration on a separate panel which is itself mounted on rubber. When this had been done, no further difficulty of this kind was experienced.

During the laboratory investigations of the equipment, and its comparison with other types of microphones, some method of measurement of the background noise had to be devised which would give results of practical interest. The important criterion is evidently the ratio of the speech volume to the background noise in the output circuit. In order to measure this, it is necessary first to define exactly what is meant by the ratio concerned. A logical and convenient definition appeared to be the degree of attenuation, expressed as a simple current ratio, which the speech energy has to undergo before becoming only just audible through the background noise.

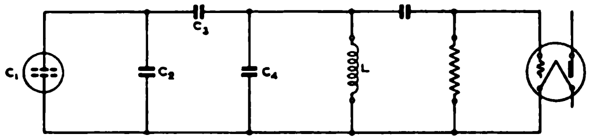

Figure 7—Noise Measuring Circuit for H. F. Condenser Transmitter Circuit.

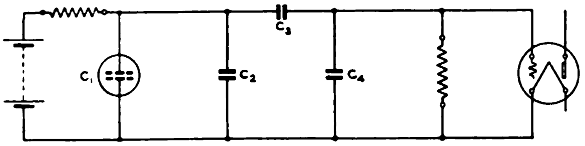

Figure 8—Noise Measuring Circuit for Ordinary Condenser Transmitter Circuit.

In order to carry out experiments on these lines, it is necessary, therefore, to have some means of attenuating the speech without interfering with the noise level; the best way of doing this depends on the particular type of microphone under test. Several cases will here be considered separately.

For the condenser microphone as described, using the high frequency equipment, the circuit shown in Figure 7 was found to be the most suitable, the H.F. voltage being induced magnetically into inductance L as before. C_1 represents the condenser microphone. By C_2 is denoted the capacity of about five yards of lead covered cable used to connect the microphone to the measuring apparatus. C_3 is a small coupling condenser; C_4 is a compensating condenser, adjusted to such a value as to give a total effective capacity across the inductance L equal to that of the condenser transmitter alone.

It is evident by inspection of the circuit that the effect of the series condenser C_3 is two-fold. In the first place, the H.F. voltage arriving at the condenser transmitter is reduced by it according to the simple attenuation ratio of the network. Secondly, any variable component of this voltage, due to changes in C_1, will itself be attenuated before arriving at the grid of the rectifier tube by this same attenuation ratio. It is thus clear, without any calculation, that the effective change in capacity at the grid in comparison with the actual change of C_1 will be proportional to the square of the attenuation coefficient. Expressed mathematically, if the resultant capacity shunting L of the system C_4, C_1, C_2, C_3 is represented by C_0,

$$\frac{dC_0}{dC_1} = \left\{\frac{C_3}{C_1 + C_2 + C_3}\right\}^2$$

This means that the ratio of the capacity change across L, due to a given speech wave impinging on the transmitter, to the capacity change produced by the same speech wave when the transmitter is directly across the inductance (as in the normal circuit) is equal to

$$\left\{\frac{C_3}{C_1 + C_2 + C_3}\right\}^2$$

Nothing else in the circuit has been altered. The total capacity across L is normal and therefore the background noise, being due to the tube, is also normal.

By this means it is clear that the speech can be attenuated at the input of the equipment by a known amount, leaving the background noise unchanged. The operation required is to adjust C_3 and C_4 until the speech is only just audible through the noise level, keeping the tuning point the same as before, and increasing the amplification to a value sufficient to render easily audible the noise background. With this adjustment, the noise level, and not lack of speech volume, is the limiting factor to the audibility of the speech.

The expression

$$\left\{\frac{C_1 + C_2 + C_3}{C_3}\right\}^2$$

is then a measure of the speech-noise ratio.

If it is desired to measure the speech-to-noise ratio of the condenser transmitter, using the normal circuit of Figure 1, the easiest circuit to employ is that shown in Figure 8.

It will be evident by reference to the diagram, that the effect of this arrangement, as before, is to reduce the effective change in capacity between the grid and filament of the amplifier tube by a known ratio in comparison with the actual change in capacity of the transmitter. As before, to keep the circuit conditions constant, and therefore the background noise at its normal value, the resultant capacity between grid and filament is made equal to the original capacity of the transmitter.

For frequencies of the order of 1,000 cycles, at which the conductances due to the leak resistances may be neglected in comparison with the capacitances of C_1 and C_4, the attenuation coefficient is given approximately by the factor

$$\left\{\frac{C_3 + C_4}{C_3}\right\}\left\{\frac{C_1 + C_2}{C_1}\right\}$$

as C_2 is very small compared with C_3 in practice. As in the previous case, the measurement is carried out by adjusting the values of the capacities until the speech is only just audible through the noise. The speech-noise ratio is then given by

$$\left\{\frac{C_3 + C_4}{C_3}\right\}\left\{\frac{C_1 + C_2}{C_1}\right\}$$

When testing a microphone of the carbon type, it is in general impossible, or very difficult, to attenuate the speech directly in a known ratio without also changing the background noise, except by increasing the distance between the speaker and the microphone. This latter method is in general not satisfactory because, among other difficulties, the speech waves may become of the same order of magnitude as the room noise. The problem was finally solved by allowing the speaker to talk into two equidistant microphones simultaneously; one, the apparatus under test, and the other, any good type of carbon microphone. Separate amplifier systems were used, and the gains adjusted until the volume indicator showed equal output volumes. The microphone to be tested was then put into a different room in a small soundproof box, the speech output of the comparison microphone amplifier having been switched into a series connection with the amplifier output of the microphone under test. The final step was to attenuate the former output until it just sank into the background noise. As the attenuation required was of the order of 40 decibels, the noise due to the comparison apparatus could be neglected. The resulting background was due entirely to the tested microphone, of which the noise was unchanged in extent. As the two speech volumes had initially been adjusted to be equal, it is evident that the speech-noise ratio of the instrument under test was equal to the attenuation added to the comparison microphone.

Some experimental results on the present equipment may be of interest:

Output Volume. The sensitivity of the equipment is given exactly by Figure 9, but more useful information is probably conveyed by stating that with an average speaker at a distance of five feet from the instrument the output level is minus 20 decibels. (As zero level corresponds to 5.9 milliwatts, minus 20 decibels corresponds to a maximum instantaneous peak power of 0.059 milliwatts.)

Frequency Characteristics. Tests have been made at the London Laboratory on the complete equipment by the standard thermophone method. The results show that the high frequency circuit compared with the ordinary method of using the transmitter, produces a change of less than 2 decibels in the characteristic at all frequencies up to 10,000 cycles. An overall characteristic of the complete high frequency equipment is shown in Figure 9. Up to 8,000 cycles, the characteristic lies within ± 1½ decibels, and above that there is a small rise which is an asset rather than otherwise, owing to the deficiencies of receiving apparatus.

Background Noise. Measurements of the speech-to-noise ratios, as defined above, of the high frequency equipment, and also of several well-known types of microphone, are given below, on the basis of the same normal speaker at a distance of 5 feet from the apparatus.

	Comparative Speech-noise Ratios Decibels	Improvement Introduced by the new equipment Decibels
"Standard" double button carbon microphone.	40	20
High sensitivity condenser transmitter (ES.619 type)...	46	14
MS.1670 transmitter employed in the circuit of Figure 1....	37	23
MS.1670 transmitter with high frequency equipment (minimum observed)............	60	..
High quality carbon microphone without diaphragm.........	41	19

In practice these results have been found to mean that no background noise can be detected under conditions of normal operation in the studio—a very important improvement over other types of apparatus.

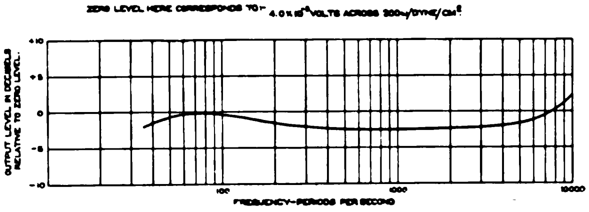

Figure 9—Overall Characteristic of Equipment.

In addition to the above tests, experiments were made under normal studio conditions for detection of non-linear distortion, if present. At the same time, a high quality diaphragmless carbon microphone was in operation at the side of the condenser transmitter equipment. Under conditions in which the former instrument was caused to blast by the brass band in the studio, no overloading whatever could be detected in the condenser transmitter apparatus.

Carrier Current Systems and Their World-Wide Application

By J. S. JAMMER

Carrier Engineer, International Standard Electric Corporation, New York

IN 1925 there was but one carrier current system in Australia. Now, there are in that country 51 such systems which have been furnished by the International Standard Electric Corporation. In addition, Spain is using, or is planning to use in the immediate future, 18 Standard Electric Carrier Systems; New Zealand has five and Japan, South Africa, Poland, France, Argentine, Mexico, Brazil, Cuba and Norway have one or more. Such a tremendous application of these systems throughout the world clearly indicates that the carrier method of providing high-grade telephone and telegraph channels is considered a sound commercial proposition.

Carrier is no longer an experiment but has taken its place along with the cables, open wire lines and radio as one unit in a group of communication systems. Early installations of carrier demonstrated very quickly that the fundamental design of the systems is such as to make it readily adaptable to the varied conditions encountered in the international field. The economic advantages of carrier as well as the high grade of performance were quickly grasped not only by the operating units of the International Telephone and Telegraph Systems but by Government Communication Administrations and privately operated telephone companies.

A small portion of the carrier equipment used in the International field has been made by the Western Electric Company at Chicago (U.S.A.) but the greater portion by far has been supplied by the Standard Telephones and Cables, Limited, London. While a carrier system is not complex to install or maintain, it does require a very high degree of precision and skill in manufacture and it has been gratifying to note that on occasions where portions of one system have been produced in two separate factories, the units fit together as a complete system as accurately as if they had been selected for the purpose.[1]

Now that carrier has come to be universally adopted, it seems desirable to review briefly the method on which these systems operate and to outline the various types of systems which are manufactured by the companies of the International group.

Fundamentals of Carrier Operation

Briefly, a carrier system is a means of obtaining more than one telephone or telegraph circuit from a given pair of wires. Such multiplex systems are termed "carrier" because they use alternating currents of comparatively high frequencies which are, in a sense, used to carry the messages. Each channel uses a different carrier frequency. These currents of different frequencies are transmitted over the same line and are separated at the sending and receiving ends by means of selective circuits.

This action of transmitting impulses of different frequencies over a given medium without mutual interference and the separation of the different frequencies for the purposes of reception might possibly be made more clear if we consider the analogy of the ordinary radio receiving set. In this latter case we have a number of broadcasting stations transmitting on different frequencies through a single medium but the receiver can be tuned, or in other words, adjusted to be efficient only at the frequency of the particular message involved. If we carry the analogy still further, the multiplex transmission used in carrier systems and the separation of the different frequencies is similar to the breaking up of white light into its various frequency components by means of a prism.

The fundamental steps involved in effecting carrier transmission either of telephone or telegraph signals consists of first, generating each of the high frequency currents to be used as carriers, then impressing upon each carrier the variations characterizing telephone or telegraph signals. This later action is termed "modulation." The next step consists of separating the several modulated carrier currents at the terminals on the basis of the difference in frequencies, thus rendering multiplex operation possible. This is termed "selectivity." The final step in transmission over a carrier system consists of restoring, at the receiving end, from the modulated carrier current the original characteristics of the individual message. This process has been called "demodulation."

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[1] J. S. Jammer, "Australia First to Use Type C-2-F Carrier System," Electrical Communication, Vol. VII, No. 1, July, 1928.

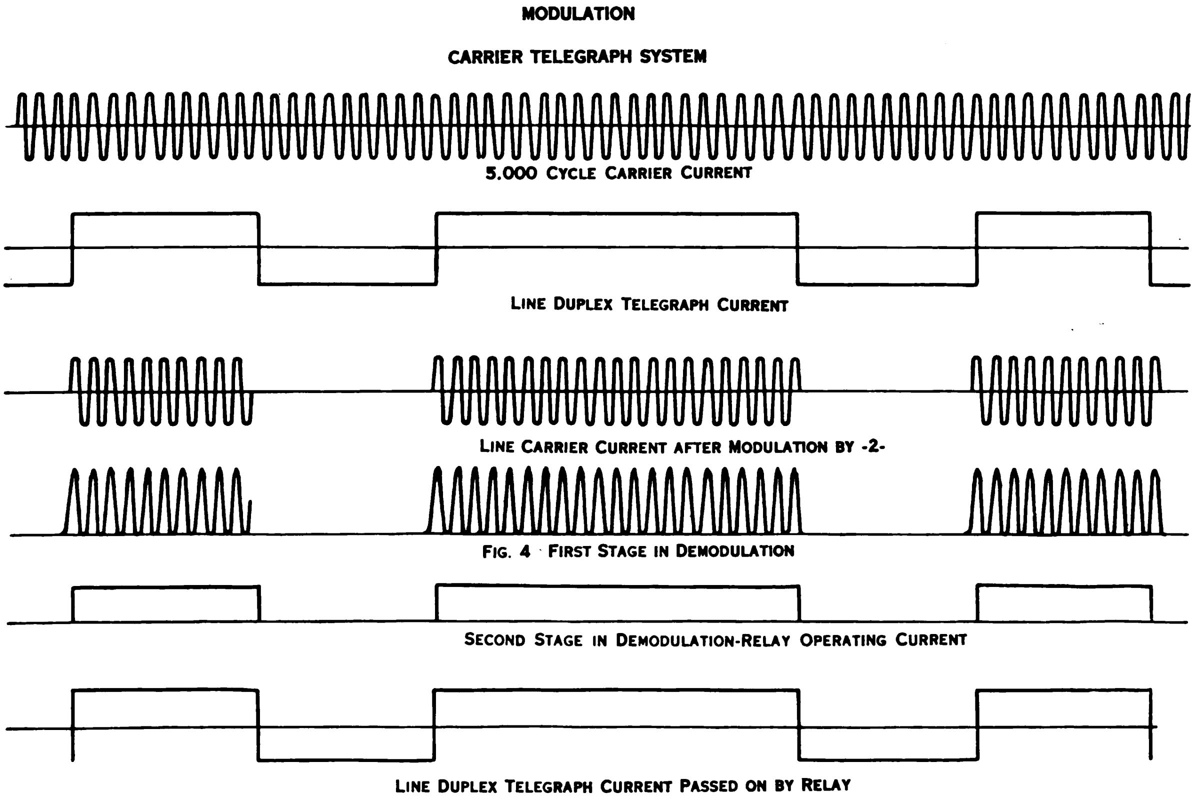

MODULATION
CARRIER TELEGRAPH SYSTEM
5.000 CYCLE CARRIER CURRENT
LINE DUPLEX TELEGRAPH CURRENT
LINE CARRIER CURRENT AFTER MODULATION BY -2-
FIG. 4 FIRST STAGE IN DEMODULATION
SECOND STAGE IN DEMODULATION-RELAY OPERATING CURRENT
LINE DUPLEX TELEGRAPH CURRENT PASSED ON BY RELAY

Figure 1—Operation of Carrier Telegraph System.

Let us consider a little more in detail the four steps mentioned above. With regard to the first step, or the generation of the carrier currents, in most cases vacuum tubes are used as oscillators. However, in the case of the voice frequency carrier telegraph system, motor generator sets have been designed to produce the carrier currents.

With regard to modulation, this action may be considered broadly as a process whereby the amplitude of a carrier current is caused to fluctuate in accordance with the variations of a signalling or voice current. This variation in amplitude results in the generation of so-called side band frequencies which are of a high frequency comparable with that of the carrier and within the band assigned to an individual channel. It is these side band currents which are actually used for the transmission of the signal.

In the present form of carrier telegraph systems, modulation consists merely of making and breaking the high frequency current in accordance with the impulses of a telegraph signal, thus sending spurts of alternating current on to the line, corresponding in duration to the dots and dashes. Figure 1 pictures the operation in a general way. First we have the unmodulated carrier or high frequency current and secondly, the telegraph signalling current. The third step shows how the high frequency current is interrupted in accordance with the impulses of the telegraph signal. These spurts of high frequency are transmitted to the distant station where they are separated from the other currents

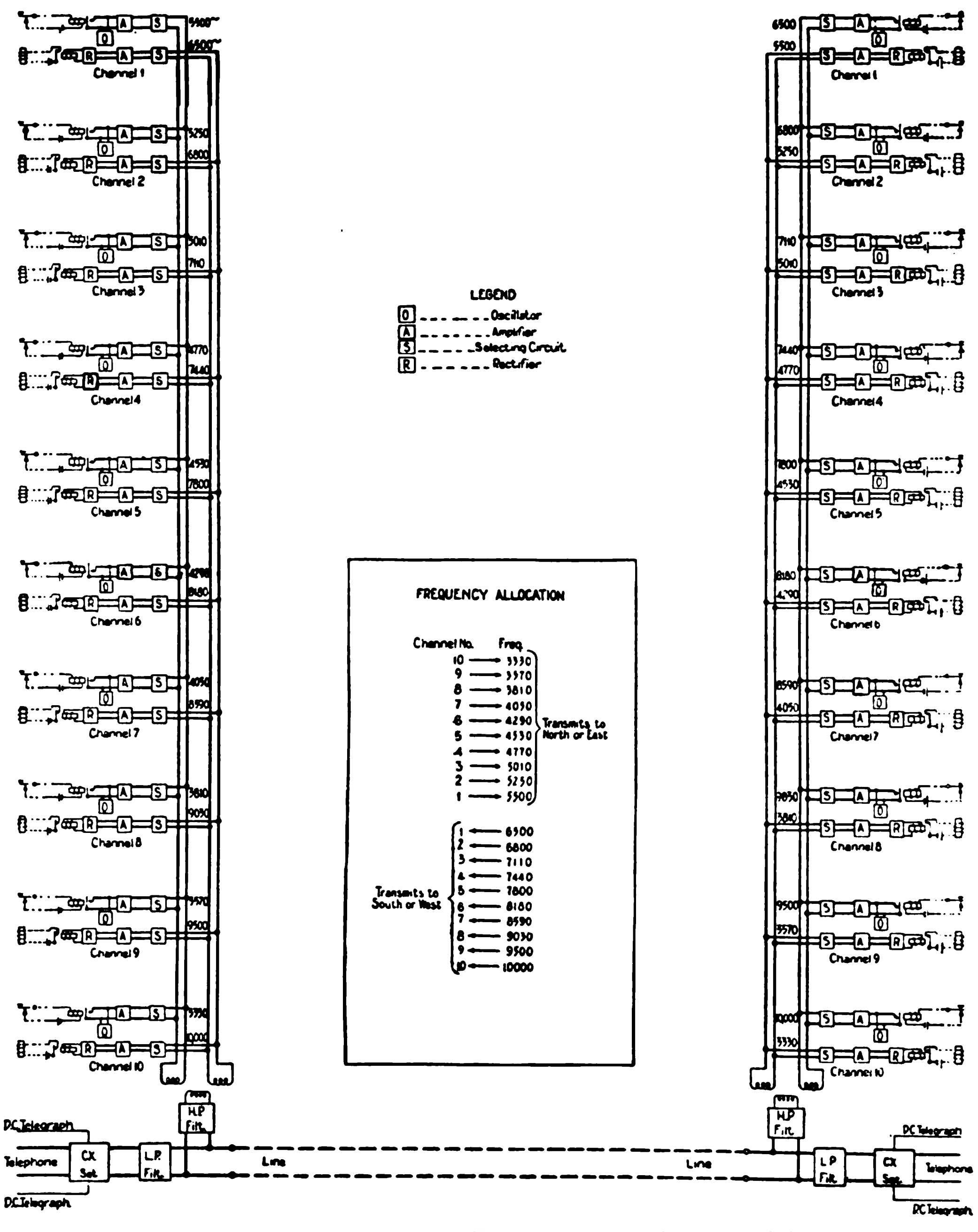


Figure 2—Schematic of Complete 10-Channel Type B Carrier Telegraph System.

which may have been on the line. The individual channel currents are then rectified and this rectified current in turn operates a relay which reproduces telegraph signals similar to those which were used at the sending station for modulating the carrier current. Figure 2 shows in simplified form the arrangement of the circuit.

In telephony, modulation consists similarly in varying the amplitude of a high frequency current in accordance with the speech current generated by the ordinary telephone transmitter. This variation in amplitude results in the generation of currents of different frequencies, the so-called side band frequencies; and it is these side band currents which are used for the transmission of the signal. Figure 3 shows graphically the process which takes place in a carrier telephone modulator. Figure 4 gives a simplified schematic circuit of a multiple telephone system.

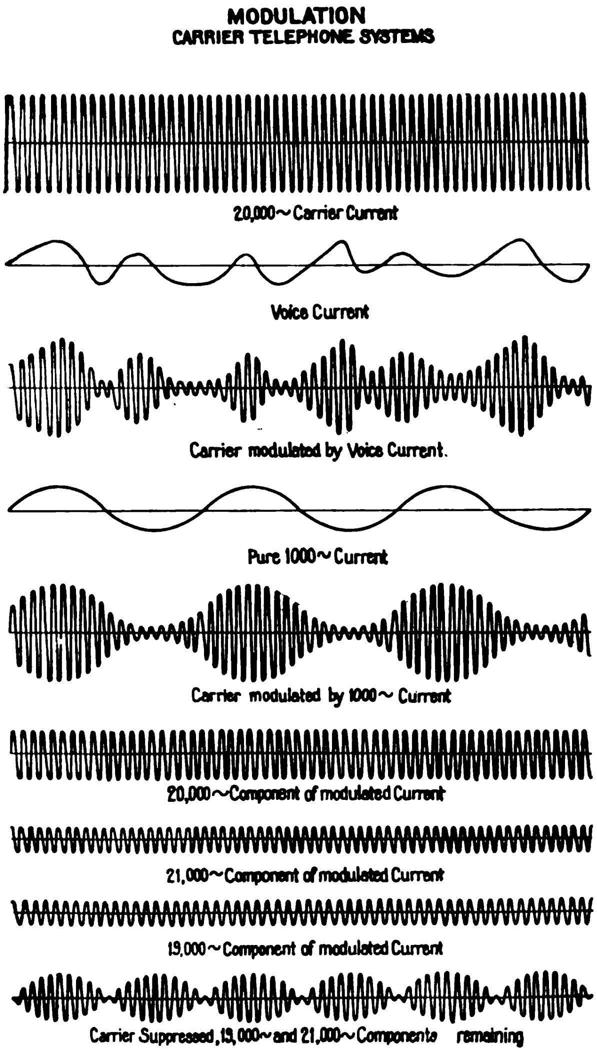

MODULATION
CARRIER TELEPHONE SYSTEMS
20,000~ Carrier Current
Voice Current
Carrier modulated by Voice Current.
Pure 1000~ Current
Carrier modulated by 1000~ Current
20,000~ Component of modulated Current
21,000~ Component of modulated Current
19,000~ Component of modulated Current
Carrier Suppressed, 19,000~ and 21,000~ Components remaining

Figure 3—Modulation of Carrier Telephone Systems.

Let us turn now to the third step mentioned above, namely, "selectivity." In telephony and communication systems generally, frequencies are used for transmission which vary from a few cycles, as in telegraphy, through the telephone range of approximately 200 to 2,500 cycles, and upward throughout our present carrier range which has been limited to about 30,000 cycles. Even higher frequencies are used for radio transmission. In fact, light waves may be similarly regarded, and their vibration frequencies of many millions of millions of cycles may be considered as the upper extreme of the frequencies with which we are accustomed to deal in daily life. As has been mentioned before, the analogy to light offers, furthermore, a convenient conception of selectivity. It is of course well known that the various colors may be selected from each other by colored glass, or by the action of a prism on white light, thereby separating the various color-frequencies composing it, red, orange, yellow, green, etc., to form a rainbow or frequency spectrum. In a similar manner the electrical frequency range may be considered as a frequency spectrum, extending in the carrier case from a frequency of about 3,000 to 30,000 cycles; and electrical selecting circuits or filters may be employed to pick out a frequency or band of frequencies and to suppress the adjacent frequencies as desired. In this way the different frequencies or bands of frequencies resulting from the modulation of different carrier currents may be applied to a single circuit, and picked apart at the receiving end of a system to be individually treated or demodulated.

Selecting circuits are employed at both the transmitting and receiving ends of carrier systems to separate the various channels and to prevent interference with the normal telephone circuit. They consist of inductance coils and condensers connected in such a manner that certain groups or bands of frequencies are transmitted; usually, they are constructed to be non-adjustable and are mounted so that only the terminals are accessible.

We come now to the fourth step in carrier transmission, namely, demodulation. In the carrier telegraph sysem, relatively simple means of demodulation are employed. As noted in connection with modulation, the line current may be considered as acting in "spurts" of single frequency alternating current. This current, after being selectively received in its proper tuned circuit, is amplified and finally led to a vacuum tube amplifier-rectifier. The tube is so connected that when there is no current input there is no corresponding output current. When the received carrier current is applied to the input, amplification takes place only during the positive half of the alternating current wave. This current may be analyzed into various frequency components, chief of which is a direct current. By means of a shunt condenser, the high-frequency components are suppressed and the direct current, corresponding in duration to the original signalling pulse, remains to operate a relay.

Demodulation in the carrier telephone system is accomplished in a somewhat different manner and the action in general may be regarded as a shifting or displacing of frequency in the reverse direction to that in modulation.

Summarizing briefly, modulation may be thought of as elevating the band of essential speech frequencies to a position adjacent to the carrier frequency, and demodulation may be regarded as a process of restoring this band to its normal position in the frequency scale.

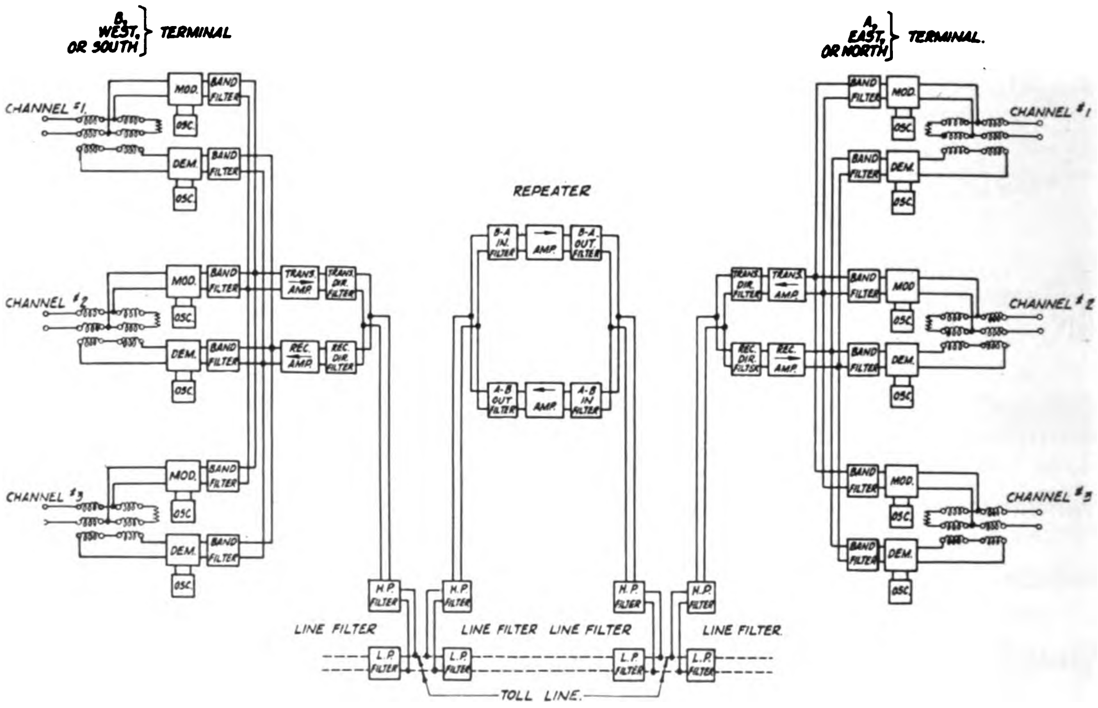


Figure 4—Simplified Schematic of a Multiple Telephone System.

As mentioned previously, carrier systems utilize a range of frequencies above those used for normal telephone service; and in order to prevent interference between the normal telephone channel and the carrier channels, so-called "line filters" are used to separate the carrier frequencies from the voice frequencies. This process is similar to that normally used for separating the low telegraph frequencies from the voice frequencies through the medium of a telegraph composite set.

High frequency currents superposed on line wires behave in accordance with the same general laws of transmission as the usual telephone frequency currents. Measurements of attenuation and impedance, for example, check very satisfactorily with theory. However, the attenuation of a telephone line increases rapidly with frequency and these greater line losses at carrier frequencies are offset by the amplifying action of the terminal and intermediate repeater equipment.

By using different carrier frequencies for transmission in opposite directions and thus eliminating the necessity of line balance, relatively large terminal and repeater amplifications are possible.

Carrier Application

Carrier systems are mostly employed on open wire non-loaded lines. Practice has shown that very little, if any, alteration in the usual line construction is required for the installation of one or two systems on a pole line; but if it is desired to utilize a line at maximum efficiency, which means installing the greatest possible number of carrier channels, it is sometimes necessary specially to transpose the lines to reduce carrier frequency crosstalk. As a rule, if a number of carrier systems can be profitably used on a given line, the cost of additional transpositions is slight in comparison with the gains which may be derived by employing carrier.

Cable circuits give rise to a much higher transmission loss than open wire circuits at carrier frequencies; hence it is desirable to use lines involving the minimum of cable. A certain amount of intermediate cable on open wire lines is, as a rule, unavoidable, but carrier systems will operate satisfactorily through moderate lengths of leading-in cable. If a long section of cable is encountered, it is necessary to load the cable for carrier frequencies. Loading units are available as required for this purpose.

The economy in using carrier systems depends largely upon the length and type of circuits required. On the basis of the present average labor and material costs in the carrier using parts of the world, it seems that single channel carrier telephone systems will be cheaper in first cost and involve lower annual charges than open wire or cable circuits for distances greater than, say, 40 miles, and three-channel telephone systems will "prove in" for distances of, say, 150 miles or more. Suppose, for instance, that three telephone circuits are required over a distance of 400 miles; that a pole line exists on the route; and that the three circuits can be obtained by stringing two pairs of copper wires to form a phantom group. In this case, in order to favor the copper circuits, let us charge against them only the cost of the wire, insulators and labor, neglecting any portion of the cost of poles and crossarms. Let us also assume, for this hypothetical case, that the effective life of the aerial line will be ten years with a 35% scrap value, and that the telephone repeaters and carrier equipment will depreciate 100% in ten years. This latter assumption is very conservative as the carrier gear is rugged, has no moving parts and, except for the possibility of obsolescence, could well be used effectively for twenty years or more.

For comparative purposes, figures representing costs will be given in arbitrary units. On this basis, with a cost of 200 units per mile for the copper wire, the 400-mile phantom group (comprising two pairs) will cost, say, 160,000 units, and let us add 4,500 units for the repeaters required to make the channels a 10 TU equivalent. We thus have a total first cost of, say, 164,500 units for the aerial circuits. The carrier system, which will provide as good or better grade service, will cost approximately 85,000 units so that, by its use, a net saving in first cost roughly of 80,000 units may be effected. Annual charges may be better appreciated in tabular form:

Annual Charge	Rate	Amount			
		Aerial Line	Telephone Repeaters	Total for Aerial Circuits	Carrier
			First Cost		
		160,000	4,500	164,500	85,000
			Annual Charges		
Interest	8 %	12,800	360	13,160	6,800
Taxes	1.5%	2,400	67	2,467	1,275
Insurance	.5%		23	23	425
Administration	.5%	800	23	823	425
Depreciation(Line)	4.5%	7,200			
Depreciation (Repeaters)	7 %		315	7,515	
Depreciation (Carrier)	7 %				5,950
Maintenance (Line)	4.0%	6,400			
Maintenance (Repeaters)	10.0%		450	6,850	
Maintenance (Carrier)	7.0%				5,950
Total		29,600	1,238	30,838	20,825

Thus it is seen that for this example, which is intended to represent the average, carrier as compared with aerial circuits presents a tremendous economic advantage, being roughly half the first cost of aerial circuits and effecting approximately a 30% reduction in annual charges.

Where the stringing of additional circuits on existing pole lines increases the chance of failure on the pole line or adds abnormally to maintenance costs, carrier systems will prove in on distances even shorter than those mentioned. These systems, because of simplicity of installation and compactness of the equipment, find application also for short distance working to meet temporary requirements as well as in cases where through their use the installation of toll cable or other expensive plant may be deferred. In a number of cases, in fact, it has been found that the savings in annual charges made possible by the use of carrier systems and the consequent postponement of large expenditures for new lines, results very quickly in writing off the first cost of the carrier equipment.

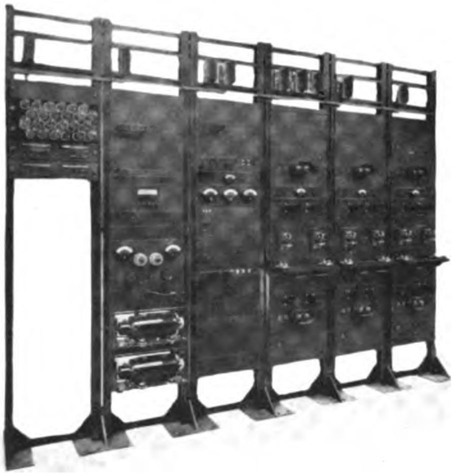


Figure 5—Voice Frequency Carrier Telegraph System—Front View of Terminal Equipment for 6-Channels.

The increased circuit facilities provided by carrier systems are of the same high standard as those obtained through the use of the best grade of long distance circuits of the more usual forms. The carrier circuits are stable and reliable and provide a greater degree of secrecy and freedom from ordinary interference than do open wire circuits. Carrier channels terminate in the usual switching facilities and are fully interchangeable with the usual trunk circuits and present the same degree of flexibility of operation.

There are three types of carrier systems manufactured by the International's associated companies, namely, voice frequency carrier telegraph, high frequency carrier telegraph and high frequency carrier telephone.

Voice Frequency Telegraph

The voice frequency carrier telegraph system has been designed primarily for use on cable circuits for providing a number of telegraph channels within the voice frequency range. It employs one or more circuits of a telephone cable where idle circuits are available or where some of the telephone circuits required to carry the peak telephone load are idle during a part of the day. The system is arranged for four-wire working and makes use of voice frequency repeaters, as in ordinary telephony.

Operating on a four-wire basis, the same carrier frequencies can be utilized for communication in both directions. The actual number of duplex channels that can be made available depends to some extent upon the nature of the cable. In the case of extra light loaded cable, it is possible to obtain twelve duplex telegraph channels over two cable pairs. The system, in special cases, can be used also for two-wire working, either on cable circuits or open wire lines; but one group of carrier frequencies must be used for transmitting in one direction and another group for transmitting in the opposite

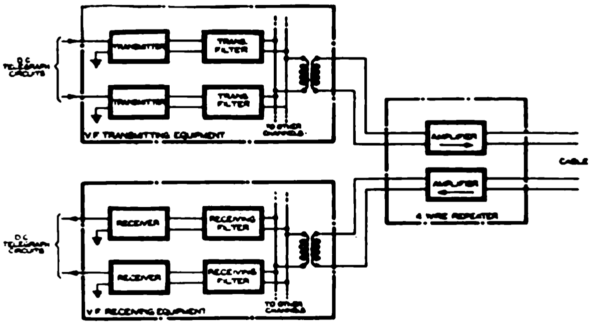


Figure 6—Voice Frequency Telegraph System—Schematic Diagram of Terminal for 4-Wire Operation. (Showing Two Channels Only in Each Direction.)

direction, so that the number of duplex channels which can be provided on a single pair is halved. Figure 5 shows the assembly of apparatus comprising a voice frequency carrier telegraph system and Figure 6 shows a simplified diagram of the circuit.

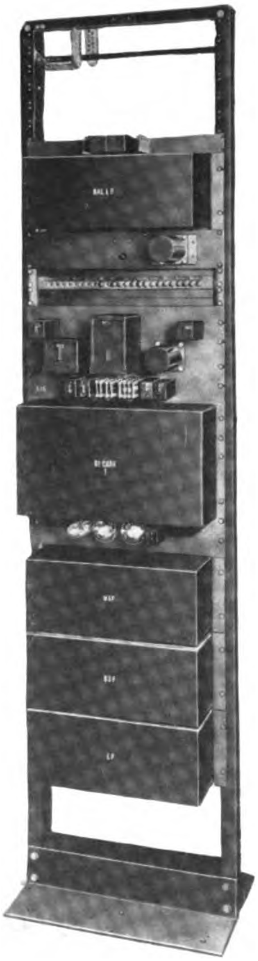
The high frequency telegraph system has been designed for use on open wire lines and will provide ten duplex channels in addition to the facilities normally provided by the wires. The system uses a band of frequencies between three and ten kilocycles and is arranged for two-wire working only, different carrier frequencies being used for transmission in the two directions.

Where copper wires are used as single telegraph circuits, an economic study indicates that a tremendous saving can be effected if two such wires are combined to form a telephone trunk and telegraph facilities are derived through the use of a carrier telegraph system superposed on the wires as a pair. Such a case recently has been met with in Australia where two grounded telegraph wires were in operation on the transcontinental line between Adelaide and Perth. In order to provide a transcontinental telephone circuit, these two wires will be used as a metallic circuit for telephone service with a superposed carrier telegraph. When completed, there will be three carrier telegraph systems in operation in Australia which, in tandem, extend from Sydney to Perth, a total distance of approximately 3,000 miles. Figure 2 shows a simplified diagram of a ten channel carrier telegraph system.

Telephone Carrier

Four types of carrier telephone systems are now available to meet the various requirements. Two of these systems provide one extra telephone channel and are known as single channel carrier systems designated as type D and type C-2-F. There are also two types of systems, which provide three additional telephone channels and which are known as type C-N-3 and type C-S-3.

Taking up these systems in turn, the Type D single channel system has been especially developed for use on comparatively short lines. It is a relatively inexpensive and economical system which as a rule proves in on distances of more than twenty-five or thirty miles and is suitable on distances of 200 to 250 miles, depending upon the size of the conductors available.



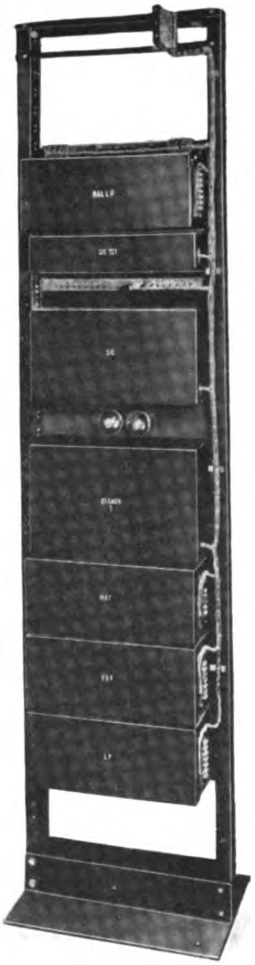


Figure 7—Front View. *Figure 8—Rear View.*
D-1 Carrier Telephone System Terminal Equipment.

Because of the short distance involved, the line is not, as a rule, subjected to severe variation and as a result, the system requires no daily adjustments. Because of this and the fact that the equipment is compact and readily portable, this system may be used also to meet temporary service requirements, inasmuch as the equipment can readily be shifted from one office to another.

The frequency range of the type D system is approximately from three to ten kilocycles and because of this comparatively low frequency, it is possible to operate a large number of systems of this type on the same pole line without excessive retransposition. In cases where the saving is sufficient, it is possible to transpose a pole line so as practically to fill it with type D equipment, which often finds application on heavily overloaded routes prior to the introduction of toll cables. Figures 7 and 8 show the form in which the equipment comprising a type D terminal is mounted, and Figure 9 shows a schematic of the circuit.

For circuits requiring an additional telephone channel of a length greater than can be handled by the type D system, the type C-2-F carrier telephone system is used. This system has been designed to provide one two-way telephone channel in addition to the existing voice frequency telephone and telegraph circuits; and, while the system will prove in from a cost standpoint at distances of from 100 to 150 miles, it can be extended to operate up to distances of roughly 750 miles. Here again the equipment is completely self-contained and, since it employs approximately the same frequencies as the type D system, very little daily maintenance is required. The chief application of the type C-2-F systems has been either as feeders to trunking centers or as forerunners to three channel systems in cases where it is desired to test the potential traffic requirements on a given route.

Since the equipment comprising the C-2-F system is self-contained, it oftentimes is found useful where temporary relief on special occasions is required, or where traffic is growing rapidly or suffers seasonal variations. Figures 10 and 11 show the assembly of the terminal and the repeater equipment and Figures 12 and 13 show simplified schematics of the terminal and repeater circuits.

The type C-N-3 and C-S-3 carrier telephone systems provide three two-way telephone channels in addition to the facilities obtained from existing lines. They are similar in every respect except that the frequency bands allotted to the various channels in the two systems have been staggered to simplify transposition. Suppose, for instance, it is desired to operate two three-channel systems on the two side circuits of a phantom group. Without excessive transposition, the crosstalk at carrier frequencies between two such closely associated physical circuits would ordinarily be great; and, in order to overcome this difficulty, the frequency bands allotted to the system operated on one side circuit are arranged to be staggered between the bands allotted to the system on the other side. In this way any crosstalk which may occur between the two lines will not cause interference between the systems.

These three channel systems provide the same

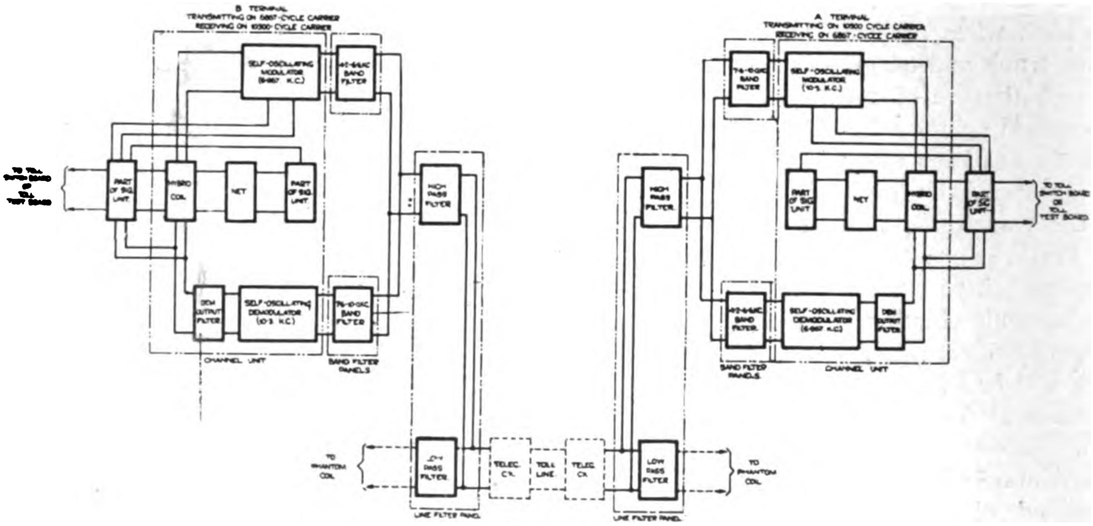


Figure 9—Schematic of D-1 Carrier Telephone System.

high grade transmission as is obtained from the single channel systems; they terminate in the switchboard in the usual manner and are operated exactly the same as any other high grade long distance trunk.

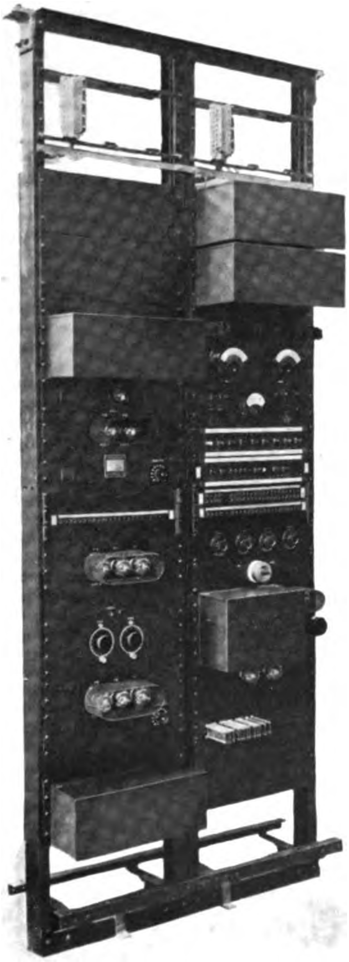


Figure 10—C-2-F Carrier Telephone System—Terminal Equipment.

As a rule, a three-channel system will prove in on relatively short distances and, through the use of carrier repeaters, its range can be extended up to any limit. The longest three-channel system now in service in the International field is between Sydney and Brisbane, a distance of about 750 miles.

Figures 14 and 15 show the terminal and repeater equipment of the three-channel system and Figure 4 gives a simplified general schematic of the two terminals with one intermediate repeater.

All of the carrier telephone systems employ the single side band suppressed carrier method of transmission. The carrier is suppressed by using what is known as a balanced or "push-pull" modulator. This consists of two vacuum tubes arranged with a common filament circuit and the input circuit so designed that the voice current is introduced in a push-pull manner making the potential on the grid of one tube positive and the other negative at a particular instant. The carrier supply is introduced so that the instantaneous potentials on both tubes are equal and of the same polarity.

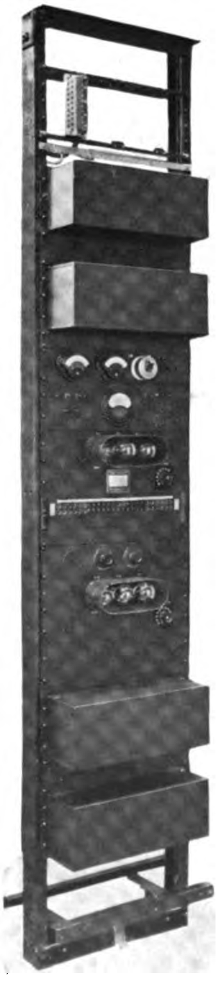


Figure 11—C-2-F Carrier Telephone System—Repeater Equipment.

If, therefore, the general characteristics of the two tubes are similar, the output current due to the carrier supply alone will be equal for each tube circuit, and the combined output induced in the secondary of the transformer circuit can be made zero by proper connection of the coils. The effect is, therefore, to suppress the carrier frequency itself. This is true not only for the steady-state with no voice input, but even when the voice current is being received on the input and the circuit is effectively unbalanced, with the voice, and side band frequencies flowing in the output. The action involves the fact that the carrier frequency currents in the two output circuits are at all times oppositely directional, whereas the product terms resulting in the side band currents are so phased as to produce cumulative action.

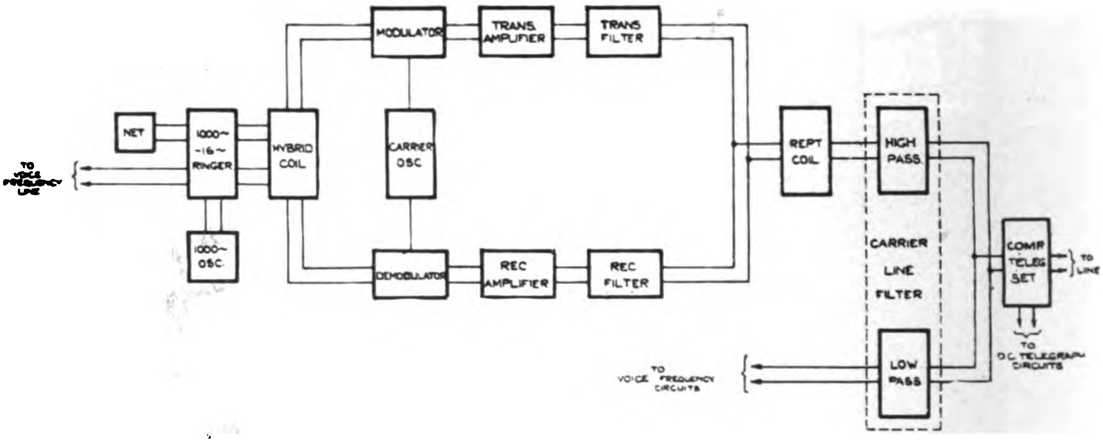


Figure 12—C-2-F Carrier Telephone System—Layout of Terminal.

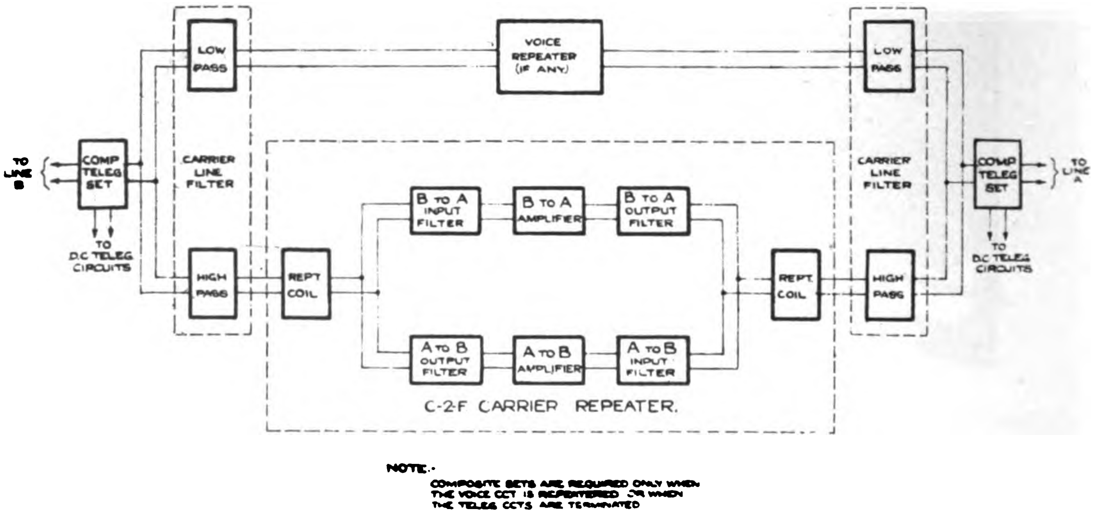


Figure 13—C-2-F Carrier Telephone System—Layout of Repeater.

By transmitting but a single side band, it is possible to keep the energy level of the side band component well above the noise level on the line and at the same time not overload the terminal and repeater equipment. Another feature of the suppressed carrier method of transmission is the improved stability obtained over a system in which the carrier is transmitted.

With the exception of the voice frequency carrier telegraph, which is normally a four-wire system, all of the carrier systems operate on two wires with a so-called group frequency method of operation. Using a different group of frequencies in the two directions simplifies the transposition problem since only far-end crosstalk is involved and, in addition, enables the circuits to be worked at greater overall gains. A channel of communication for ordinary telephone or telegraph service must of course be two way and it can be made so either by using the conductors bi-directionally or by using two pairs of conductors, one pair for transmission in one direction and the other, for transmission in the opposite direction. This latter is the so-called "four-wire circuit" and in voice frequency telephone operation, permits the use of much higher gains than does a two-wire circuit. Consequently a long four-wire repeater circuit can be operated at a low transmission equivalent. That advantage is economically realizable with small gauge conductors in long cables but it is not so with open wire lines when used for voice frequency operation. A big advantage of the carrier systems is that they are designed on a basis that is equivalent to a four-wire circuit but actually operate on two wires. Each carrier channel has two carrier frequencies, one for operation in the A to B direction and the other for the B to A direction. It is apparent, therefore, that through the agency of the carrier the advantages of four-wire operation can be and, in actual practice, is economically secured for aerial lines. This

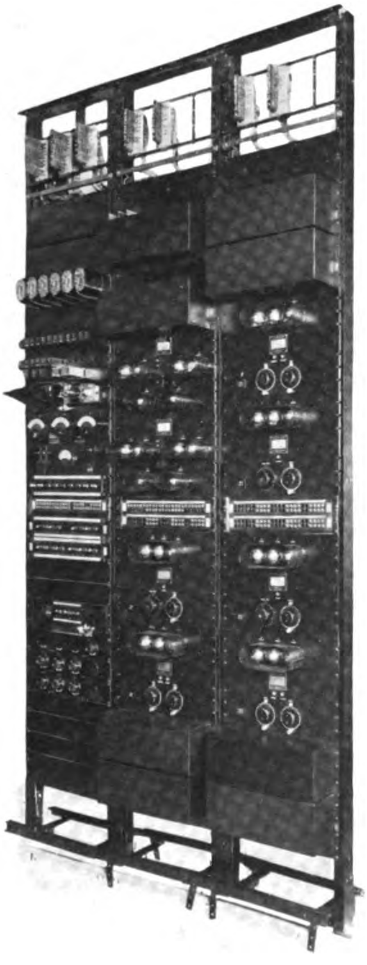


Figure 14—Three Channel Carrier Telephone System—Terminal Equipment.

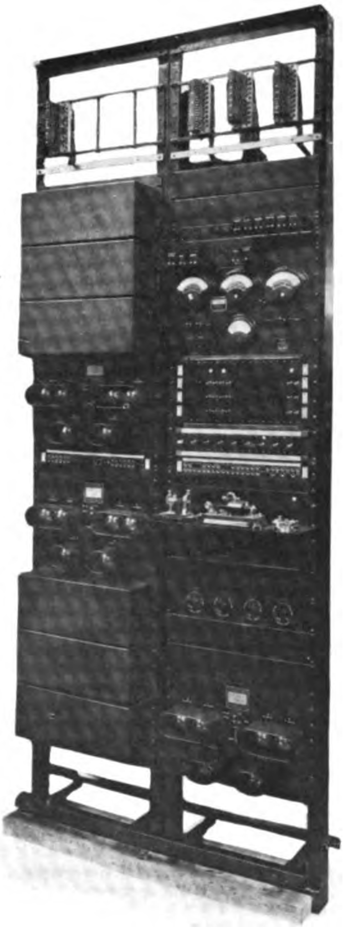


Figure 15—Three Channel Carrier Telephone System—Repeater Equipment.

means that for very long trunk circuits an exceptionally good equivalent can be obtained over a carrier channel while the repeatered physical circuit operating on the same pair of wires may necessarily, because of the difficulties in repeater balance, be operated at an equivalent many times that of the carrier channel. For this reason in some cases a long existing trunk line is broken up to provide intermediate circuits and a carrier system superimposed to take care of the through traffic. Such a condition has recently been met with between Sydney and Melbourne where the through circuits are now provided entirely by carrier and the original physical circuits have been broken up to take care of the way stations.

With the exception of the type D single channel system, the carrier telephone systems utilize one thousand cycle ringing current. The ringing to and from the switchboard is carried out in the normal way which, in most cases, involves the use of 16 cycle current but on an outgoing ring this 16 cycle current operates a relay chain which impresses interrupted 1,000 cycle current on the carrier channel, the 1,000 cycle ringing current being supplied from a local generator. At the distant terminal the incoming 1,000 cycle ringing current operates a relay chain which in turn causes the local ringing current to be transmitted to the switchboard. The ringing system is not an inherent part of the carrier channel and, if the carrier is used as an intermediate portion of a long trunk on which voice frequency ringing is employed, it is not necessary to provide ringing equipment with the carrier as it will effectively transmit any frequencies between 250 and 2,500 cycles. The type D system employs a form of voice frequency ringing but in order to avoid the necessity of providing a local 1,000 cycle ringing generator, the ringing current is obtained by shifting the carrier frequency at the transmitting terminal 1,000 cycles away from the carrier frequency at the receiving terminal and thus producing the same net result as is obtained through the ordinary forms of the voice frequency ringing systems.

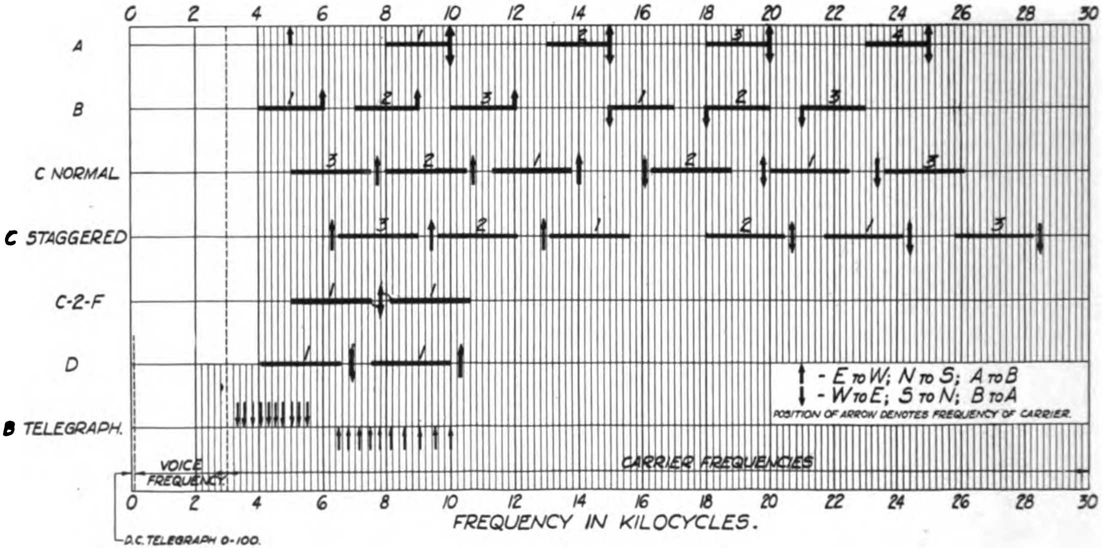


Figure 16—Frequency Allocation of Carrier Systems.

In order that the frequency allocation of the various types of carrier systems may be more readily appreciated, Figure 16 shows graphically the bands of frequencies allotted to the various types of systems.

Circuits Available Through Carrier Operation

Having considered briefly the principles and economics of carrier operation, as well as various types of systems, it seems pertinent to point out some of the facilities which may be provided by these improved efficiency systems. By improved efficiency is meant not only improved quality, transmission and stability—features which have been mentioned above—but the increased number of circuits which can be obtained from existing copper lines.

For example, using the more widely known communication systems, one telephone and two telegraph circuits can be obtained from one pair of wires; but, using a three channel carrier telephone system on these same wires, four telephone and two telegraph channels or, in the case of a carrier telegraph system, one telephone and twelve telegraph channels may be obtained. Of these twelve telegraph channels, two are the direct current circuits which can be operated under favorable conditions at a speed of, say, 60 words per minute. *The ten carrier telegraph channels, however, can each be operated with a printing telegraph system which will provide four telegraph message channels per carrier channel,* so that we can have as many as 40 telegraph messages being transmitted over the carrier telegraph system simultaneously. Each of these 40 messages can be transmitted at the rate of 60 words per minute. Furthermore, since the channels are duplex, we can transmit 40 messages in each direction at the same time, or 80 telegraph messages simultaneously. Including the two duplex direct current channels, we then have one pair of wires being used for the simultaneous transmission of one telephone message and eighty-four telegraph messages.

If we use a pair of wires for telegraph purposes only, the telephone channel can be replaced by a two-wire six channel voice frequency carrier telegraph system, so that we obtain a total of sixteen carrier channels which, when equipped with four channel printing telegraph apparatus and added to the two direct current channels, give us a total of sixty-six two-way channels, or permit of the simultaneous transmission of 132 messages on a single pair of wires.

Carrier facilities can be carried still further. By using on one pair of wires a three channel carrier telephone system and superimposing a voice frequency carrier telegraph system on each carrier telephone channel, we can obtain a total of 170 two-way channels or transmit over a single pair of wires, 340 telegraph messages simultaneously.

Let us consider the maximum facilities which can be obtained from four copper wires comprising a phantom group. If the circuits are used mostly for telephone service, we provide two physical and one phantom telephone circuit; in addition a three channel carrier telephone system can be superposed on each physical circuit, giving a total of nine telephone and four telegraph channels from four wires. If more telegraph channels are required, a voice frequency telegraph system can be used on one of the carrier telephone channels and we net eight telephone channels and 52 two-way telegraph channels. If we replace another telephone channel by a second telegraph system, we net seven telephone channels and one hundred two-way telegraph channels; similarly, we can net six telephone and 148 two-way telegraph channels of five telephone and 196 two-way telegraph channels. If we go to the extreme of telegraph application by using all the telephone channels for telegraph purposes, we can provide on four wires a total of 364 two-way telegraph channels which will permit of the simultaneous transmission of 728 messages. As each of these channels is capable of carrying 60 five-letter words per minute, we are thus enabled to transmit a total of 43,680 words per minute over four wires.

The Brussels International Telegraph Conference September, 1928

By SIFFER LEMOINE

IN THE year 1925, an International Telegraph Conference was held in Paris to consider and pass upon certain changes in the International Telegraph Regulations.

Many changes in these Regulations were agreed to, but one proposal which was of fundamental importance, had to be deferred owing to difficulty in arriving at a satisfactory solution. This proposal, which for many years had claimed the earnest study of the governments of the world, and of the private communication interests, involved the question of charging for code messages. In view of its importance, the proposal was considered at a special Conference of the International Telegraph Union which was held at Cortina, Italy, in August, 1926. It was also brought up at the Radio Telegraph Conference held at Washington in the fall of 1927 and was considered at the special Conference of the International Telegraph Union which was held at Brussels under the auspices of the Belgian Government in September, 1928. The latter Conference was attended by delegations of a great majority of the governments who are members of the International Telegraph Union and by an unofficial delegation of the United States Government as well as by representatives of the principal cable, telegraph and radio telegraph companies of the world.

At the Brussels Conference, a change in the International Telegraph Regulations relating to coded messages, to take effect October 1, 1929, was agreed on. While far from ideal, a great number of the governments represented felt that the change was the best which was possible under the circumstances. The following proposition was accordingly adopted:

Ordinary messages in plain language are to be charged for as at present and code messages are to be divided into two categories, namely, Category A and Category B.

Category A is to consist of code words not exceeding ten letters, including at least one vowel if the word is composed of at most five letters; at least two vowels if the word is composed of six, seven or eight letters; and three vowels if the word is composed of nine or ten letters. Words composed of nine or ten letters must contain at least one vowel in the first five letters and two vowels in the remainder of the word; or vice versa, two vowels in the first five letters and one vowel in the remainder of the word.

Category B is to contain code words of not more than five letters without any restriction as to their formation.

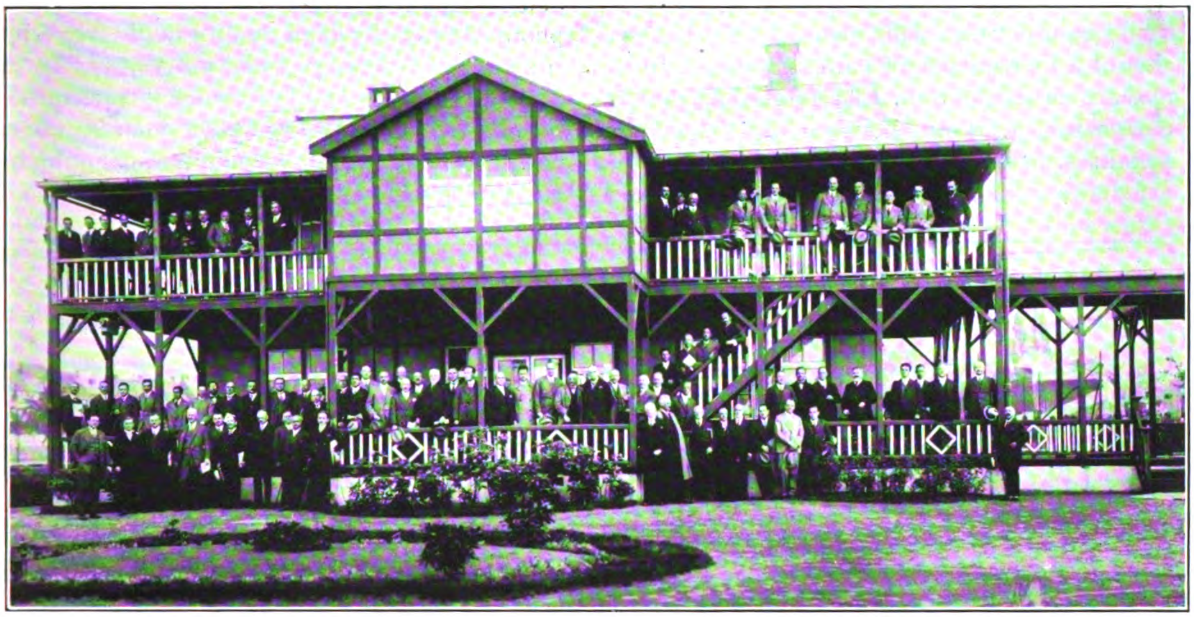
The service indication of words in Category B is to be "CDE" which indication is not charged for. There is to be a minimum of four words per message in this class. Numbers or groups of numbers are not permitted in this category.

Telegrams in Category A are charged for at the full rate; in Category B, the charge is to be two-thirds of the full rate for messages in the extra-European system. For messages in the European system the rate for Category B is to be three-fourths of the full rate. The European system includes all countries of Europe and those territories outside of Europe which are declared by the respective administrations to belong to the European system. The extra-European system includes countries other than those in the European system, and therefore applies to telegrams between North and South America or between North and South America on the one side and all other parts of the world on the other.

Mr. Goldhammer, Vice-President of the Commercial Cable Company, was one of the American Government Delegates. All America Cables was represented by Messrs. Davidson and C. H. Russell, and the Commercial Cable Company by Messrs. H. F. Russell, Heiskell and Lindow.

The Belgian Government was most hospitable in its arrangements for the entertainment of the delegates, and the courtesy of the Government and the excellence of the arrangements were greatly appreciated.

On the afternoon of September 19th, a large number of delegates visited the plants of the Bell Telephone Manufacturing Company at Antwerp and Hoboken, and were afterwards entertained at tea at the Club House at the Company's sports grounds. The arrangements for this visit were excellent in every respect.



Visit of the Delegates of the International Telegraph Conference to the Club House of the Bell Telephone Manufacturing Company, Antwerp.

Hoboken, September 19, 1928.

Transformers as Band Pass Filters

By E. K. SANDEMAN

European Engineering Department, International Standard Electric Corporation

FOR practical purposes it is possible to replace a transformer having self capacity by a network which consists of a half section of a known type of band pass filter. In the absence of dissipation, therefore, the transformer when working between its image impedances, passes a band of frequencies with no attenuation (i.e., with uniform voltage step-up).

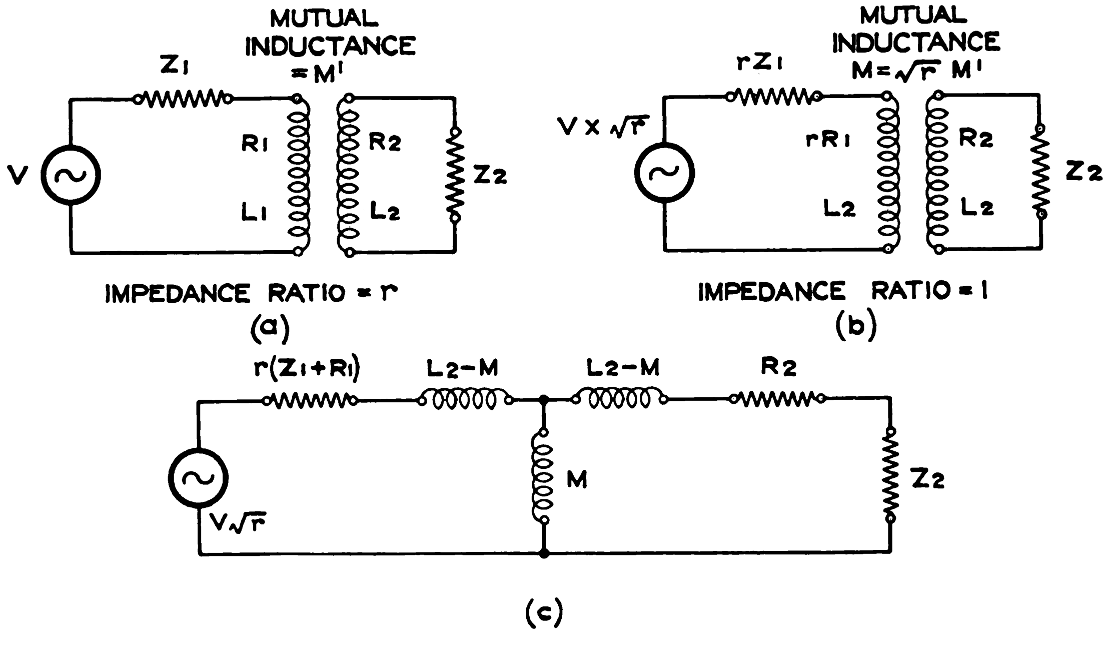


Figure 1—Transformer and Equivalent Networks.

Design formulæ are developed for a simple transformer working between its image impedances, and for a transformer associated with a series capacity. The ideal theory is applicable in practice to carrier and long wave transformers for frequencies lying between 5,000 and an upper limit of approximately 100,000 cycles for impedances the order of 20,000 ohms, and to audio frequency transformers for ordinary telephony. It fails for high quality audio frequency transformers passing wide ranges, and is of doubtful value for radio frequency transformers for wave lengths below 3,000 metres, except where the valve anode impedances are not higher than 10,000 ohms.

Part I—Theory of the Transformer Considered as a Band Pass Filter

In an article on Telephone Transformers,[1] W. L. Caspar shows that the performance of a transformer may be conveniently determined by considering the performance of a unity ratio transformer derived from it. In Figure 1 at (a) is shown a transformer operating between impedances Z_1 and Z_2, having primary inductance and resistance L_1 and R_1, secondary inductance and resistance L_2 and R_2, a mutual inductance M, and an impedance ratio $r=\frac{L_2}{L_1}$. At (b) and (c) are shown the stages by which the circuit at (a) is replaced, first, by one containing an equivalent unity ratio transformer and finally, by one containing an equivalent T network, the conditions to be satisfied at each replacement being that the current in Z_1 shall be unaltered.

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[1] "Telephone Transformers," Electrical Communication, Vol. II, No. 4.

In the case where the frequency and the self capacity are such that the effect of the self capacity has to be taken into account, and where uniform transmission over a range of frequencies is required, the circuit may be represented as in Figure 2. Here C is the total self capacity, including primary self capacity transferred to the secondary.

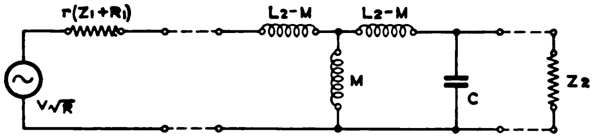


Figure 2 (at left)—Equivalent Network of Transformer Having Self Capacity.

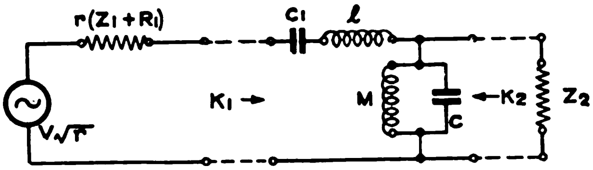


Figure 3 (at right) Approximate Network for Transformer Having Capacity.

Neglecting R_2 and inserting an ideal transformation according to filter theory, it may be shown that if (L_2-M) is very small compared to M, as is actually the case in practice, the circuit of Figure 3 may be used to replace the circuit of Figure 2 without appreciable alteration of performance. The quantity $2\ (L_2-M)$ will be called the magnetic leakage inductance l.

Since $l=2\ (L_2-M)$

and $M=K\sqrt{L_1\,L_2}=KL_2$ in a unity ratio transformer, it follows

that $l=\frac{2}{K}(1-K)\ M$.

The leakage inductance l is now all on the same side of M. Experiment shows that for all practical purposes, valid results will be obtained by assuming R_2 to be directly in series with Z_2.

Referring to the article by Mr. Otto J. Zobel in the Bell System Technical Journal for January, 1923, page 42, it is evident that this case corresponds to a ladder filter structure of type VI. 2.

In order that such a filter may transmit a band of frequencies with zero attenuation it must be terminated at half section, mid series or mid shunt, and the termination faced by the corresponding iterative impedance. The network in Figure 3 may be regarded as being terminated on the left hand (primary) side, at mid series, and on the right hand (secondary) side at mid shunt. Under these conditions,

$$l=\tfrac{1}{2}L'_1,\quad M=2\ L_2,\quad C=\tfrac{1}{2}C_2.$$

Hence if f_1 is the lower cut-off frequency and f_2 the upper cut-off frequency, $\overline{R}$ being the mean line resistance (i.e., at $f=\sqrt{f_1\,f_2}$), from page 42 of Mr. Zobel's article,

$$l=\frac{R}{2\pi(f_1+f_2)},\quad M=\frac{2(f_2-f_1)R}{4\pi\ f_1^2},\quad C=\frac{1}{2\pi(f_2-f_1)R}$$

$$(1)\qquad\qquad (2)\qquad\qquad (3)$$

The full elements of the filter are

$$L'_1=\frac{R}{\pi(f_1+f_2)},\quad L_2=\frac{(f_2-f_1)R}{4\pi\ f_1^2},\quad C_2=\frac{1}{\pi(f_2-f_1)R}$$

$$(4)\qquad\qquad (5)\qquad\qquad (6)$$

Mid series impedance (Primary image impedance).

$$K_1=\left(Z_1\ Z_2+\frac{Z_1^2}{4}\right)^{\frac{1}{2}}$$

$$= \left[L'_1\, j\omega \text{ x } \frac{1}{Cj\omega + \dfrac{1}{L_2 j\omega}} + \frac{(L'_1\, j\omega)}{4} \right]^{\frac{1}{2}}$$

$$= \left[\frac{\dfrac{R\ 2\pi f}{\pi(f_1+f_2)}}{\dfrac{2\pi f}{\pi(f_2-f_1)R} - \dfrac{1}{\dfrac{(f_2-f_1)R.2\pi f}{4\pi\ f_1^2}}} - \frac{R^2 4\pi f^2}{4\pi^2(f_1+f_2)^2} \right]^{\frac{1}{2}}$$

$$= \left[\frac{\dfrac{fR^2}{f_1+f_2}}{\dfrac{f^2}{f(f_2-f_1)} - \dfrac{f_1^2}{f(f_2-f_1)}} - \frac{R^2\, f^2}{(f_1+f_2)^2} \right]^{\frac{1}{2}}$$

$$= \left[\frac{f^2\,(f_2-f_1)}{(f_1+f_2)\,(f^2-f_1^2)} - \frac{f^2}{(f_1+f_2)^2} \right]^{\frac{1}{2}} R \ldots\ldots\ldots(7)$$

and when f is the geometric mean of the two cut-off frequencies (i.e., at mid band when $f^2 = f_1\, f_2$),

$$K_1 = \left[\frac{f_1\, f_2^2 - f_1^2\, f_2}{(f_1+f_2)\,(f_1\, f_2 - f_1^2)} - \frac{f_1\, f_2}{(f_1+f_2)^2} \right]^{\frac{1}{2}} R$$

$$= \left[\frac{f_2}{f_2+f_1} - \frac{f_1\, f_2}{(f_1+f_2)^2} \right]^{\frac{1}{2}} R$$

$$= \frac{f_2}{f_2+f_1} R = \text{primary image impedance at mid band} \ldots\ldots\ldots\ldots(8)$$

Mid shunt impedance (Secondary image impedance).

$$K_2 = \frac{Z_1\, Z_2}{K_1}$$

$$= \left[\frac{1}{\dfrac{(f_1+f_2)\,(f^2-f_1^2)}{f^2\,(f_2-f_1)} - \dfrac{(f_1+f_2)\,(f^2-f_1^2)^2}{f^2\,(f_2-f_1)^2}} \right]^{\frac{1}{2}} R \ldots(9)$$

and when $f^2 = f_1\, f_2$

$$K_2 = \frac{\dfrac{f_2}{f_2+f_1} R^2}{\dfrac{f_2}{f_2+f_1} R} = R \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

That is, R is the secondary image impedance at mid band.

DEVELOPMENT OF DESIGN FORMULÆ

Generally, for a given core, the self capacity C and the coupling factor K do not vary appreciably for appreciable changes in the number of turns on each winding.

As a preliminary step in design, it is first necessary that these quantities, which form the basic design data, should be determined by making measurements on a transformer, experimental or otherwise, using the core in question.

The problems facing the transformer designer are dictated chiefly by the required frequency range to be passed and the impedances between which the transformer is required to operate.

Since $l = \dfrac{2}{K}(1-K)M$, equation (1) may be written

$$\frac{2}{K}(1-K)M = \frac{R}{2\pi(f_1+f_2)} \ldots\ldots\ldots\ldots\ldots(11)$$

Repeating (2) and (3)

$$M = \frac{2(f_2-f_1)R}{4\pi\ f_1^2} \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

$$C = \frac{1}{2\pi(f_2-f_1)R} \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

Since C and K are constants of the transformer, the above three equations relate four variables R, M, f_1 and f_2; there is thus one degree of freedom permitting either a choice of the value of any one of these variables or a choice of the relation between any two of them. It is convenient to derive from equations (11), (12) and (13) certain dependent relations which are most immediately applicable in each of the different initial conditions imposed.

$$\text{From (11), } f_2+f_1 = \frac{R}{\dfrac{4\pi}{K}(1-K)M} \ldots\ldots\ldots(14)$$

$$\text{From (13), } f_2-f_1 = \frac{1}{2\pi\ R\ C} \ldots\ldots\ldots\ldots(15)$$

$$\therefore\ 2\ f_2 = \frac{K\ R}{4\pi(1-K)M} + \frac{1}{2\pi RC} \ldots\ldots(16)$$

$$2\ f_1 = \frac{K\ R}{4\pi(1-K)M} - \frac{1}{2\pi\ RC} \ldots\ldots(17)$$

Substituting (15) and (17) in (12),

$$M = \frac{\dfrac{2\,R}{2\pi\,R\,C}}{\dfrac{4\pi}{4}\left[\dfrac{K\,R}{4\pi(1-K)M} - \dfrac{1}{2\pi\,R\,C}\right]^2}$$

$$\therefore MC\left[\frac{K^2\,R^2}{16(1-K)^2M^2} - \frac{K}{4(1-K)MC} + \frac{1}{4R^2C^2}\right] = 1$$

$$\therefore \quad \frac{M\,C\,K^2\,R^2}{16(1-K)^2M^2} - \frac{K}{4(1-K)} + \frac{M}{4R^2C} = 1$$

$$\therefore \quad \frac{M^2}{4R^2C} - \frac{M\,K+4(1-K)M}{4(1-K)} + \frac{C\,K^2\,R^2}{16(1-K)^2} = 0$$

$$\therefore \quad \frac{1}{R^2C}\,M^2 - \frac{4-3K}{1-K}\,M + \frac{CK^2\,R^2}{4(1-K)^2} = 0$$

$$\therefore M = \frac{\dfrac{4-3K}{1-K} \pm \sqrt{\dfrac{(4-3K)^2}{1-K} - \dfrac{K^2}{(1-K)^2}}}{\dfrac{2}{R^2C}}$$

$$\therefore M = \frac{R^2C}{2(1-K)}\left[4-3K \pm \sqrt{(4-3K)^2-K^2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(18)$$

The negative sign of the root is taken in order to make f_1 positive; this may be seen from equation (26).

Again from (12), $4\pi\,M\,f_1^2 = 2\,f_2\,R - 2\,f_1\,R$

and from (13), $\dfrac{1}{\pi C} = 2\,f_2\,R - 2\,f_1\,R$

$$\therefore \quad 4\pi\,M\,f_1^2 = \frac{1}{\pi C}$$

$$\therefore \quad M = \frac{1}{4\pi^2\,C\,f_1^2} \quad \ldots\ldots(19)$$

From (13), $R = \dfrac{1}{2\pi\,(f_2-f_1)\,C}$ ....(20)

Substituting (19) and (20) in (11)

$$\therefore \quad \frac{\dfrac{2}{K}(1-K)}{4\pi^2\,C\,f_1^2} = \frac{R}{2\pi(f_1+f_2)}$$

$$\therefore \quad \frac{\dfrac{2}{K}(1-K)}{4\pi^2\,C\,f_1^2} = \frac{1}{4\pi^2\,(f_2^2-f_1^2)\,C}$$

$$\therefore \quad f_2^2 - f_1^2 = \frac{f_1^2}{\dfrac{2}{K}(1-K)}$$

$$\therefore \quad f_2^2 = \frac{1+\dfrac{2}{K}(1-K)}{\dfrac{2}{K}(1-K)}\,f_1^2$$

$$= \frac{1-\dfrac{K}{2}}{1-K} = \frac{2-K}{2-2K}\,f_1^2 \quad \ldots\ldots(21)$$

$$\therefore \quad f_2 = \sqrt{\frac{2-K}{2-2K}}\,f_1 \quad \ldots\ldots(22)$$

From (21) $(2-2K)\,f_2^2 = (2-K)\,f_1^2$

$$\therefore \quad 2\,f_2^2 - 2\,f_2^2\,K = 2\,f_1^2 - f_1^2\,K$$

$$\therefore \quad 2\,f_2^2K - f_1^2\,K = 2\,f_2^2 - 2\,f_1^2$$

$$\therefore \quad K = \frac{2\,f_2^2 - 2\,f_1^2}{2\,f_2^2 - f_1^2} \quad \ldots\ldots(23)$$

Again, from (4)

$$f_1 = \tfrac{1}{2}\left[\frac{K\,R}{4\pi(1-K)M} - \frac{1}{2\pi\,R\,C}\right]$$

$$= \frac{1}{2R}\left[\frac{K\,R^2}{4\pi(1-K)M} - \frac{1}{2\pi C}\right] \quad ..(24)$$

From (18),

$$R^2 = \frac{2\,M(1-K)}{C\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]} \quad \ldots(25)$$

Substituting from (25) into (24)

$$\therefore f_1 = \frac{1}{2\sqrt{\dfrac{2\,M(1-K)}{C\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]}}}$$

$$\left[\frac{2\,KM(1-K)}{4\pi(1-K)MC\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]} \quad \frac{1}{2\pi C}\right]$$

$$f_1=\tfrac{1}{2}\sqrt{\frac{C}{2M}\cdot\frac{1}{1-K}\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]}$$

$$\left[\frac{K}{2\pi C\left[4-3K-\sqrt{(4-3K)^2-K^2}\right]}{}^{1}+\frac{1}{2\pi C}\right]$$

$$f_1=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$\left[\frac{K}{4-3K-\sqrt{(4-3K)^2-K^2}}-1\right]\ldots\ldots\ldots(26)$$

Similarly from equation (16) it may be shown that

$$f_2=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$\left[\frac{K}{4-3K-\sqrt{(4-3K)^2-K^2}}+1\right]\ldots\ldots\ldots(27)$$

Equations (25) and (26) may be written

$$f_1=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}$$

$$\left[\frac{K}{\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}}-\right.$$

$$\left.\sqrt{(4-3K)-\sqrt{(4-3K)^2-K^2}}\right]\ldots\ldots\ldots(28)$$

$$f_2=\frac{1}{4\pi\sqrt{MC}}\sqrt{\frac{1}{2-2K}}$$

$$\left[\frac{K}{\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}}+\right.$$

$$\left.\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}\right]\ldots\ldots\ldots(29)$$

It is evident from equation (22) that division of equation (29) by equation (28) should afford the relation $\frac{f_2}{f_1}=\sqrt{\frac{2-K}{2-2K}}$

As this forms a valuable check it has been included below.

$$\frac{f_2}{f_1}=\frac{\frac{K}{A}+A}{\frac{K}{A}-A}\quad\text{where } A=\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$\therefore\ \frac{f_2}{f_1}=\frac{K+A^2}{K-A^2}$$

$$=\frac{K+4-3K-B}{K-4+3K+B}\quad\text{where } B=$$

$$\sqrt{4-3K-\sqrt{(4-3K)^2-K^2}}$$

$$=\frac{4-2K-B}{4K-4+B}$$

$$\therefore\ \frac{f_1}{f_1+f_2}=\frac{4K-4+B}{4K-4+B+4-2K-B}$$

$$=\frac{4K-4+\sqrt{16-24K+K^2}}{2\ K}$$

$$=\frac{2K-2+\sqrt{2K^2-6K+4}}{K}$$

$$=\frac{2-2K-\sqrt{(2-K)\ (2-2K)}}{-K}$$

$$=\frac{2-2K-(2-2K)}{2-2K-2+K}\sqrt{\frac{2-K}{2-2K}}$$

$$\therefore\ \frac{f_1}{f_1+f_2}=\frac{1-\sqrt{\frac{2-K}{2-2K}}}{1-\ \frac{2-K}{2-2K}}=\frac{1}{1+\sqrt{\frac{2-K}{2-2K}}}$$

$$\therefore\ \frac{f_2}{f_1}=\sqrt{\frac{2-K}{2-2K}}$$

Part II—Design of Unequal Ratio Transformers

The design of an actual unequal ratio transformer is thus preceded by the design of an hypothetical unity ratio transformer operating between equal impedances R.

The value R should be considered to include not only the impedance of the load into which the transformer operates, but also the value of the internal resistances of the windings, R_1 and R_2.

The value of R in Part I represents the secondary impedance into which the actual transformer operates while the secondary inductance of the actual transformer

$$L_2 = \frac{M}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (30)$$

The primary inductance

$$L_1 = \frac{L_2}{r}$$

where r is the impedance step up which should satisfy the relation

$$r = \frac{Z_2 + R_2}{Z_1 + R_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

It is to be noted that the mutual inductance of the unequal ratio transformer is always less than that of the equal ratio transformer from which it is derived in the ratio of $\sqrt{r}$. This does not mean, as might appear to be the case, that the resonances are altered. The parallel resonance is really secondary resonance, and the secondary inductance is unaltered. The series resonance is unaltered because the secondary leakage inductance (for constant K) is unaltered, and the primary leakage inductance, seen through the transformer, is stepped up to the same value as in the unity ratio case.

The following four cases of limited design requirements may be solved directly from the theory in Part I.

Case I. To Design a Transformer to give flat reproduction between two impedances Z_1 *and* Z_2. *Given self capacity* C *and coupling factor* K.

Although termed impedances Z_1 and Z_2 are considered to be of zero angle.

An estimation of the value of R_1 and R_2 should be made, when r follows from equation (31) and also

$$R = Z_2 + R_2.$$

Then from equations (18), (24), and (16)

$$M = \frac{R^2 C}{2(1-K)}\left[4 - 3K - \sqrt{(4-3K)^2 - K^2}\right]$$

$$f_1 = \frac{1}{2}\left[\frac{KR}{4\pi(1-K)M} - \frac{1}{2\pi RC}\right]$$

$$f_2 = f_1 + \frac{1}{2\pi RC}$$

also $$L_2 = \frac{M}{K}$$

$$L_1 = \frac{L_2}{r}$$

Case II. To Design a Transformer to pass a band of a given width. Given $f_2 - f_1$, C *and* K.

From (11) the secondary impedance

$$R = \frac{1}{2\pi(f_2 - f_1)C}$$

also

$$M = \frac{R^2 C}{2(1-K)}\left[4 - 3K - \sqrt{(4-3K)^2 - K^2}\right]$$

$$L_2 = \frac{M}{K}$$

$$L_1 = \frac{L_2}{r} \quad \text{where } r = \frac{R}{Z_1 + R_1}$$

f_1 and f_2 are calculated by the same formulæ as in Case I.

Case III. Given f_1, C *and* K.

From (19)

$$M = \frac{1}{4\pi^2 C f_1^2}$$

From (22)

$$f_2 = \sqrt{\frac{2-K}{2-2K}}\, f_1$$

$$R = \frac{1}{2\pi(f_2 - f_1)C}$$

L_1 and L_2 follow as in Case II.

Case IV. Given f_2, C *and* K.

From (22)

$$f_1 = \sqrt{\frac{2-2K}{2-K}}\, f_2$$

From (19)

$$M=\frac{1}{4\pi^2 C f_1^2}$$

$$R=\frac{1}{2\pi (f_2-f_1) C}$$

L_1 and L_2 follow as in Case II.

It is evident that none of the above four cases leads directly to a complete provision of the requirements which would be put forward in the general practical case, although for some individual practical cases they afford satisfactory solutions.

The general practical case evidently involves at the same time, the width of the passed range and also its location.

The width of the passed band involves the self capacity C and the secondary impedance R independently of any other variables, as is brought out by equation (15).

When the value of f_2-f_1 has been determined by the value of C (probably dictated by the case used) and the choice of R, the location of the range is determined by the value of K, as is shown by equation (22). This may perhaps be made clearer by the following:

Put $f_2-f_1=D$, so that $f_1=f_2-D$;

then

$$f_2=\sqrt{\frac{2-K}{2-2K}}\,f_1=\sqrt{\frac{2-K}{2-2K}}\,(f_2-D)$$

$$\therefore \quad f_2=\frac{D}{\sqrt{\frac{2-K}{2-2K}}-1}$$

It is therefore evident that if the application of the four ideal cases above leads neither to a solution nor to an acceptable compromise, steps must be taken to improve either C or K as indicated above.

A further extension of the lower cut-off frequency is possible by tuning the transformer; this is discussed in Part III.

It should be noted that the lower cut-off is in general not sharp, and, provided the loss at f_r, the lowest frequency in the range of interest, does not exceed whatever may be the tolerable amount, it is possible in certain cases to accept a value of f_1 higher than f_r.

The loss at f_r may be calculated as follows:

From Figure 2, the loss at f_r is equal to that caused by a bridged impedance Z between impedances of R, where Z is the impedance of M and C in parallel.

$$\text{Hence } Z=\frac{jL\omega}{1-LC\omega^2}=\frac{1}{Y}\text{ say.}$$

Loss introduced by a shunt between two impedances, Z_1 *and* Z_2.

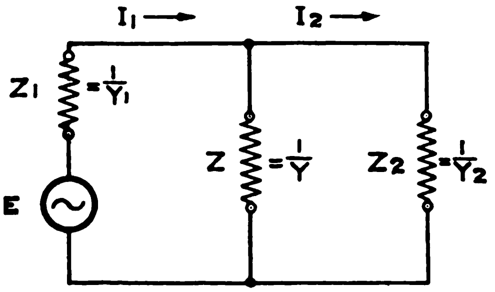


Figure 4—Illustrating Shunt Impedance.

Referring to Figure 4, in the absence of the shunt,

$$I_2=\frac{E}{Z_1+Z_2}=\frac{E}{\frac{1}{Y_1}+\frac{1}{Y_2}}$$

In the presence of the shunt,

$$I_1=\frac{E}{Z_1+\frac{1}{Y+Y_2}}$$

$$I_2=\frac{Y_2}{Y+Y_2}I_1=\frac{Y_2 E}{(Y+Y_2)\left(\frac{1}{Y_1}+\frac{1}{Y+Y_2}\right)}$$

Current ratio

$$\frac{I_2}{I_1}=\frac{E}{\frac{1}{Y_1}+\frac{1}{Y_2}}\times\frac{\frac{Y+Y_2}{Y_1}+1}{Y_2 E}$$

$$=\frac{Y+Y_1+Y_2}{Y_1+Y_2}$$

Putting $Y_1=Y_2=\frac{1}{R}=G$ the loss in TU due to the shunts M and C

$$=20\log_{10}\left|\frac{Y+2G}{2G}\right|$$

where the heavy lines indicate that only the argument of the complex quantity between them is to be taken into account.

Part III—Theory of Tuned Transformer

By inserting a condenser in series with the primary of a transformer, the passed range may be increased by the lowering of f_1.

The circuit to be considered is given in Figure 5.

Referring again to page 42 of Mr. Zobel's article in the Bell System Technical Journal, for January, 1923, it is evident that this corresponds to a ladder filter of type VII.

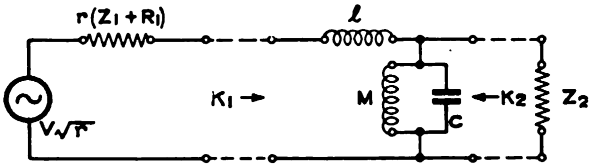


Figure 5—Equivalent Network for Transformer with Series Tuning.

As in Part I, from page 42 of the above,

$$C_1 = 2\,C_{1k} = \frac{f_2 - f_1}{2\pi\, f_1\, f_2\, R} \quad \ldots\ldots\ldots\ldots (101)$$

$$l = \tfrac{1}{2}\,L_{1k} = \frac{R}{2\pi(f_2 - f_1)} \quad \ldots\ldots\ldots\ldots (102)$$

$$M = 2\,L_{2k} = \frac{(f_2 - f_1)R}{2\pi\, f_1\, f_2} \quad \ldots\ldots\ldots\ldots (103)$$

$$C = \tfrac{1}{2}\,C_{2k} = \frac{1}{2\pi(f_2 - f_1)\,R} \quad \ldots\ldots\ldots (104)$$

The full elements of the section being

$$L_{1k} = \frac{R}{\pi(f_2 - f_1)} \qquad L_{2k} = \frac{(f_2 - f_1)\,R}{4\pi\, f_1\, f_2}$$

$$C_{1k} = \frac{f_2 - f_1}{4\pi\, f_1\, f_2\, R} \qquad C_{2k} = \frac{1}{\pi(f_2 - f_1)\,R}$$

This filter is of the constant K type and hence the mid-band image impedance is R on both sides.

Substituting in equation (103) the relation $l = \frac{2}{K}\,(1-K)M$ and repeating parts of (101), (103) and (104).

$$\frac{2}{K}(1-K)M = \frac{R}{2\pi(f_2 - f_1)} \quad \ldots\ldots\ldots\ldots (105)$$

$$M = \frac{(f_2 - f_1)R}{2\pi\, f_1\, f_2} \quad \ldots\ldots\ldots\ldots (106)$$

$$C = \frac{1}{2\pi(f_2 - f_1)R} \quad \ldots\ldots\ldots\ldots (107)$$

$$C_1 = \frac{f_2 - f_1}{2\pi\, f_1\, f_2\, R} \quad \ldots\ldots\ldots\ldots (108)$$

K and C being taken as constants, the above four equations relate five variables R, M, f_1 and f_2, and C_1; there is then one degree of freedom, as before, permitting either a choice of the value of any one of these variables or a choice of the relation between them. Also as before, it is convenient to derive certain dependent relations.

From (105 and (107)

$$\frac{2}{K}\,(1-K)\,\frac{M}{R} = CR \quad \ldots\ldots\ldots\ldots\ldots (109)$$

$$\text{whence } R^2 = \frac{2}{K}\,(1-K)\,\frac{M}{C} \quad \ldots\ldots\ldots\ldots\ldots (110)$$

$$M = R^2 C\,\frac{K}{2(1-K)} \quad \ldots\ldots\ldots\ldots\ldots (111)$$

$$\text{and } C = \frac{M}{R^2}\cdot\frac{2}{K}\,(1-K) \quad \ldots\ldots\ldots\ldots\ldots (112)$$

From (106) and (108)

$$\frac{M}{R} = C_1\, R \quad \ldots\ldots\ldots\ldots\ldots (113)$$

whence

$$R^2 = \frac{M}{C_1} \quad \ldots\ldots\ldots\ldots\ldots (114)$$

$$M = C_1\, R^2 \quad \ldots\ldots\ldots\ldots\ldots (115)$$

$$\text{and} \qquad C_1 = \frac{M}{R^2} \quad \ldots\ldots\ldots\ldots\ldots (116)$$

From (111) and (115)

$$C_1 = \frac{K}{2(1-K)}\,C \quad \ldots\ldots\ldots\ldots\ldots (116a)$$

From (106) and (107)

$$R(f_2-f_1)=2\pi\, f_1\, f_2\, M=\frac{1}{2\pi C} \quad \ldots\ldots(117)$$

$$\therefore\ f_2=\frac{1}{4\pi^2\, MC\, f_1} \quad \ldots\ldots\ldots\ldots\ldots(118)$$

Substituting in (107)

$$\therefore\ C=\frac{1}{2\pi\left(\dfrac{1}{4\pi^2\, MC\, f_1}-f_1\right)R}$$

$$\therefore\ \frac{1}{4\pi^2\, MC\, f_1}-f_1-\frac{1}{2\pi\, RC}=0$$

$$\therefore\ f_1^2+\frac{1}{2\pi\, RC}f_1-\frac{1}{4\pi^2\, MC}=0$$

$$\therefore\ 4\pi^2\, f_1^2+\frac{2\pi\, f_1}{RC}-\frac{1}{MC}=0$$

$$\therefore\ f_1=\frac{-\dfrac{1}{RC}+\sqrt{\dfrac{1}{R^2C^2}+\dfrac{4}{MC}}}{4\pi} \quad \ldots\ldots\ldots(119)$$

From (105) and (106)

$$M=\frac{R}{2\pi(f_2-f_1)\dfrac{2}{K}(1-K)}=\frac{(f_2-f_1)R}{2\pi\, f_1\, f_2} \quad \ldots\ldots(120)$$

$$\therefore\ f_1\, f_2\cdot\frac{K}{2(1-K)}=f_2^2-2\, f_1\, f_2+f_1^2$$

$$\therefore\ f_2^2-\left(2+\frac{K}{2(1-K)}\right)f_1\, f_2+f_1^2=0$$

$$\therefore\ f_2^2-\frac{4-3K}{2-2K}f_1\, f_2+f_1^2=0$$

$$\therefore\ f_2=\frac{1}{2}\left[\frac{4-3K}{2-2K}+\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_1 \quad \ldots(121)$$

$$\text{and}\quad f_1=\frac{1}{2}\left[\frac{4-3K}{2-2K}-\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_1 \quad \ldots(122)$$

Part IV—Design of a Tuned Transformer

Case V.

To design a tuned transformer to give flat reproduction between two impedances Z_1 *and* Z_2. *Given* R, *self capacity* C, *and coupling factor* K.

As in Case I, from equations (111), (116), (118) and (119)

$$M=R^2C\frac{K}{2-2K}$$

$$f_1=\frac{-\dfrac{1}{RC}+\sqrt{\dfrac{1}{R^2C^2}+\dfrac{4}{MC}}}{4\pi}$$

$$f_2=\frac{1}{4\pi^2\, MC\, f_1}$$

$$C_1=\frac{M}{R^2}$$

$$L_2=\frac{M}{K}$$

$$L_1=\frac{L_2}{r}$$

Case VI.

To design a tuned transformer to pass a band of a given width. Given f_2-f_1, C *and* K.

From (107), (111), and (116)

$$R=\frac{1}{2\pi(f_2-f_1)C}$$

$$M=R^2C\frac{K}{2(1-K)}$$

$$C_1=\frac{M}{R^2}$$

$$L_2=\frac{M}{K}$$

$$L_1=\frac{L_2}{R}$$

f_1 and f_2 may be calculated by the same formulæ as in Case I.

Case VII.

Given f_1, C *and* K.

From (121), (118), (116) and

$$f_2=\frac{1}{2}\left[\frac{4-3K}{2-2K}+\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_1$$

$$M=\frac{1}{4\pi^2\,C\,f_1\,f_2}$$

$$R=\sqrt{\frac{2}{K}\,(1-K)\,\frac{M}{C}}$$

$$C_1=\frac{M}{R^2}$$

Case VIII.

Given f_2, C *and* K.

From (122)

$$f_1=\frac{1}{2}\left[\frac{4-3K}{2-2K}-\sqrt{\frac{(4-3K)^2}{(2-2K)}-4}\,\right]f_2$$

The values of the two remaining quantities then follow as in Case VII.

Part V—Specific Examples

1. It is required to design an untuned transformer to give uniform reproduction within its pass range and to operate between impedances of 500 and 24,500 ohms. The self capacity of the transformer+the parallel capacity of the associated apparatus on the secondary side (e.g., the input of a valve) has a value of 100 micro-micro-farads, which is an average value occurring in practice. The coupling factor is .995, which is rather higher than the average value occurring in practice but which can be secured by special winding. The resistances of the low and high windings are estimated at 1,750 and 25 ohms, respectively.

The data for design of the unity ratio transformer are then

$$R=26{,}250,\quad C=10^{-10}\text{ Farads},\quad K=.995$$

Applying the formulæ for Case I,

$$M=\frac{26{,}250^2\times10^{-10}}{2(1-.995)}\left[4-3\times.995-\sqrt{(4-3\times.995)^2-.995^2}\right]$$

$$=6.88\left[1.015-\sqrt{(1.015)^2-.99}\right]$$

$$=5.6\text{ henrys}$$

$$f_1=\frac{1}{2}\left[\frac{.995\times26{,}250}{4\pi\times.005\times5.6}-\frac{1}{2\pi\times26{,}250\times10^{-10}}\right]$$

$$=\frac{1}{2}(74{,}200-60{,}600)=6{,}800\sim.$$

$$f_2=f_1+\frac{1}{2\pi\times26{,}250\times10^{-10}}$$

$$=67{,}400\sim.$$

$$L_2=\frac{M}{K}=5.625\text{ henrys}$$

$$L_1=5.625\times\frac{525}{26{,}250}=0.1125\text{ henrys}$$

$$\text{Loss at }100\sim=20\log_{10}\left|\frac{\dfrac{1}{j\,5.6\times628}+\dfrac{2}{26{,}250}}{\dfrac{2}{26{,}250}}\right|$$

$$=20\log_{10}\left|\frac{2-j\,7.45}{2}\right|$$

$$=20\log_{10}4.54$$

$$=13.1\text{ TU}$$

Such a transformer, while suitable for use in carrier wave circuits, intermediate frequency amplifiers or long wave amplifiers, would not be suitable in an audio frequency circuit which was required to transmit high quality music. As the argument immediately following indicates, it is not practically possible to construct a transformer operating into 25,000 ohms which will give an ideally uniform reproduction down to a frequency as low as say 30$\sim$, while maintaining uniform reproduction up to 10,000$\sim$. The value of K, taken above, is as high or higher than can be realised by ordinary methods of sectionalising windings and cannot therefore be increased.

Substituting the value of $K=0.995$ in equation (22)

$$f_2=\sqrt{\frac{1.005}{0.01}}\,f_1=10f_1\text{ nearly.}$$

In order to reproduce a range from 30 to 10,000 cycles, a value of K given by equation (23) must be obtained.

$$K=\frac{2\times10^8-2.30^2}{2\times10^8-30}$$

that is, greater than .999995.

In practice, for audio frequency transformers which are required to give high quality reproduction, the value of M is made larger than the value given by equation (18) and, in a particular case, may be as much as 15 times larger.

Examining the effect of this in the present case f_2, being inversely proportional to $\sqrt{M}$, is reduced from 67,400 to approximately 17,400, and similarly, f_1 is reduced to 1,750. At 30$\sim$ the loss is substantially that due to the bridged impedance M, the effect of self capacity being negligible.

The loss at 30$\sim$

$$= 20 \log_{10} \left| \frac{\dfrac{1}{j\,5.6 \times 15 \times 188.5} + \dfrac{2}{26{,}250}}{\dfrac{2}{26{,}250}} \right|$$

$$= 20 \log_{10} \left| \frac{2 - j\,1.65}{2} \right|$$

$$= 20 \log_{10} 2.06$$

$$= 6.26 \text{ TU}$$

Such a transformer does not give uniform reproduction within its pass range, but frequencies in the upper part of the audio frequency range of importance (up to 10,000$\sim$) are reproduced with uniform efficiency because the upper resonance is well above 10,000$\sim$ and because the impedance of the shunting capacity (100 $\mu\mu$F) is large (159,000 ohms at 10,000$\sim$) compared to the terminating resistance.

2. It is required to design a tuned transformer to give uniform reproduction within its pass range and to operate between impedances of 500 and 24,500 ohms.

The data for the design of the unity ratio transformer are

$R = 26{,}250,\qquad C = 10^{-10}$ farads, $\qquad K = .995.$

Applying the formulæ of Case V.

$$M = 26{,}250^2 \times 10^{-10} \times \frac{.995}{2 - 1.99} = 6.846 \text{ henrys}$$

$$f_1 = \frac{\dfrac{-1}{26{,}250 \times 10^{-10}} + \sqrt{\dfrac{1}{26{,}250^2 \times 10^{-20}} + \dfrac{4}{6.846 \times 10^{-10}}}}{4\pi}$$

$$= \frac{-3.8095 \times 10^5 + \sqrt{1.4512 \times 10'' + .05834 \times 10''}}{4\pi}$$

$$= \frac{-3.8095 + 3.8846}{4\pi} \times 10^5 = \frac{7510}{4\pi}$$

$$= 597.6\sim$$

$$f_2 = \frac{1}{4\pi^2 \times 6.846 \times 10^{-10} \times 597.6}$$

$$= 61{,}820\sim$$

It is therefore evident that, for the value of $K = .995$, it is only possible with an untuned transformer to realise a maximum ratio between f_2 and f_1 equal to about 10, but with the use of low frequency tuning this ratio may be extended to 100, an advantage of no mean value. This may be seen more directly by substituting the value of K in equations (22) and (121).

If the tuning condenser is placed on the high side of the winding,

$$C_1 = \frac{M}{R^2} = \frac{6.85}{26{,}250^2} = .994 \times 10^{-8} = .00994\,\mu\text{F}.$$

If it is placed on the low side,

$$C_1 = .00994 \times \frac{26{,}250}{525} = .497\ \mu\text{F}.$$

3. It is required to design a transformer with low frequency tuning in which

$$f_1 = 500{,}000\sim,\ K = 0.5,\ C = 40\mu\ \mu\text{F}.$$

Applying the formulæ of Case VII,

$$f_2 = \frac{1}{2}\left[\frac{4 - 1.5}{2 - 1} + \sqrt{2.5^2 - 4}\right] f_1$$

$$= 2\, f_1 = 1{,}000{,}000\sim.$$

e.g., as a radio transformer, wave lengths from 300 to 600 metres would be passed.

$$M = \frac{1}{4\pi^2 \times 4 \times 10^{-11} \times 0.5 \times 10^{12}}$$

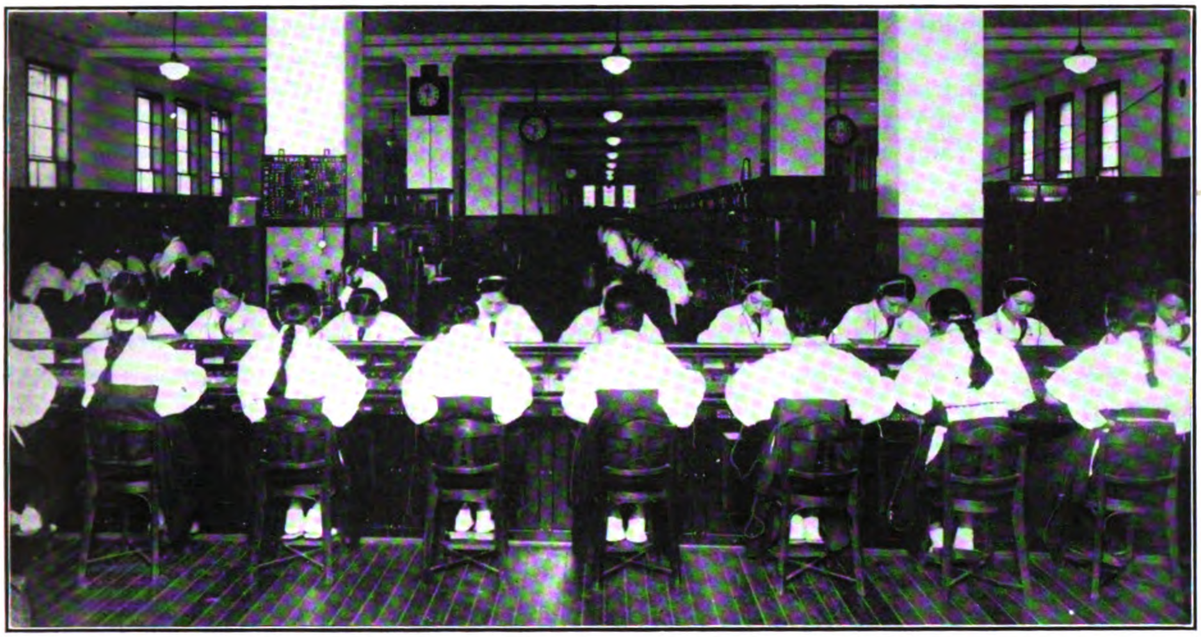
$$= 1268 \text{ micro-henrys}$$

$$R = \sqrt{\frac{2}{.5} \times .5 \times \frac{1268 \times 10^{-6}}{4 \times 10^{-11}}}$$

$$= 8000 \text{ ohms approximately.}$$

This is too low an impedance for most high frequency valves, and explains the difficulty which has been experienced in designing transformers for wavelengths below 3,000 metres, to work between impedances of the order of 20,000 or 50,000 ohms and to pass a wide band of wavelengths.

$$C_1 = \frac{1268 \times 10^{-6}}{8000^2} = 158\mu\ \mu\text{F}.$$



Toll Operating Room—No. 3 Toll Board. Tokyo Central Telephone Office. The Recording Boards Are in the Foreground.

Tokyo and Kobe Toll Cable

By SANNOSUKE INADA

Director General of Telegraph and Telephone Engineering, Department of Communications, Japan

BECAUSE of economic and technical considerations, the application of toll telephone cables heretofore has been limited in Japan to short hauls, such as Tokyo-Yokohama, Kyoto-Osaka, Osaka-Kobe and Moji-Kurosaki, where suburban toll traffic was most congested. Nevertheless, in view of the progress made in telephone transmission engineering, it was decided in connection with the third telephone expansion program of 1920, that a cable between Tokyo and Okayama could be provided economically. The circuits involve the main trunk lines of the Empire and cover a distance of approximately 800 kilometers (about 200 ri).

Work was started on the new cable in the fiscal year 1922. Although the construction schedule had to be somewhat altered, owing to the Earthquake, on the whole, the initial plan has been followed and construction has been progressing in a satisfactory way so that, of the total distance, the line between Tokyo and Kobe was opened for traffic on November first, 1928, just before the Coronation. As a result, a speedier dispatch could be arranged for important conversations relative to the Coronation, and toll conversations between Tokyo, Osaka and the others of the Six Large Cities, as well as other cities and towns along the route, can now be carried on far more easily than formerly.

Since the telephone cable just opened for traffic is one of the largest cable systems in the world, outside of the United States of America, and is an epoch-making achievement in long distance telephone communications in Japan, a summary will be given in this paper of its design features and the installation work involved, as well as plans for the future extension of the cable system.

Fundamental Considerations

Toll telephone circuits in Japan heretofore have consisted mostly of bare overhead wire lines. Bare overhead wire is, however, extremely difficult to maintain and cannot be secured absolutely against storms or various troubles arising from human acts (see Table No. 1). Moreover, the use of a mixed line, consisting of short lengths of cable and aerial bare wire, renders the quality of conversation poor.

Table No. 1—Number of Troubles per 100 Km. of Telephone Wire.

YEAR	1916	1917	1918	1920	1921	1922	1923	1924	1925	1926	1927	Ave.
No. troubles per 100 Km. of wire	4.5	4.3	5.3	4.8	5.0	6.5	2.5	4.8	4.0	3.7	4.0	4.5
Duration, Hours	23	26	32	31	41	47	19	31	23	21	23	29

The development of commerce and industry, the resulting transportation and traffic congestion, and the advancement in other fields of endeavor caused a great demand for telephone service between cities and towns separated by long distances. The demand could not be met with perfect smoothness or full satisfaction even with additions made year after year to the toll lines which then existed.

If an attempt had been made to furnish the many telephone line additions required by stringing of overhead wire, the maintenance difficulties would have been great and the cost of construction for the project as a whole would have been prohibitive. Consequently, it was found necessary to supersede aerial bare wire lines by some other form of construction.

Telephone conversations through cable, prior to the time when telephone repeaters and loading coils were developed fully, were limited to a few tens of kilometers, with consequent limitation in the use of cable circuits. Improvements in vacuum tube repeaters and loading coils, however, have made the transmission of speech, through cable circuits, possible for a distance up to 8,000 kilometers. Thus, along with the great advance in long distance speech transmission, troubles due to storms, rain, snow, etc., have been reduced with resultant economy in maintenance by the adoption of cable circuits. As a consequence, in Europe and America, various countries, one after another, are installing cable for their important toll trunks, so that the present project may be said to result from the demands of the age.

With aerial wire lines, telephone circuits may be added each year according to demand, up to the limited capacity of the pole line. Consequently the annual construction cost is comparatively, not large. In a cable, however, due to its construction, the number of circuits cannot be limited to the present need, but it is necessary to provide a large cored cable to care for future growth; and as a consequence, a greater initial investment cannot be avoided.

For the reasons mentioned, in making up the present budget for the telephone expansion project, a decision was reached to install a cable line between Tokyo and Okayama, this route being the most important of all the toll trunks. The route was divided into several divisions; and construction work has been continued since the fiscal year 1922 for each division separately so that there might be no interference with the general telephone expansion program. As a result, the portion between Tokyo and Kobe was completed this fall.

Design

Circuit. Intermediate loading coils are inserted in the cable circuit at distances of approximately 1830 meters to reduce the attenuation rate of speech current, and telephone repeater stations are employed at distances of from 100 to 150 kilometers. When the distance between two terminal stations does not exceed 400 kilometers, so-called two-wire system telephone circuits are used, each circuit consisting of two wires (a pair) of a cable and equipped with two-wire system telephone repeaters, suitably spaced. When this distance exceeds 400 kilometers, so-called four-wire system telephone circuits are used as standard, each circuit consisting of four wires (two pairs) of a cable and equipped with four-wire system telephone repeaters, suitably spaced. Thus, two-wire circuits are used between Tokyo and Nagoya; four-wire circuits between Tokyo and Kyoto, also between Tokyo and Osaka.

Speech current, attenuated in passing through a cable circuit, is amplified by telephone repeaters. It will attenuate again before reaching the receiving end, but the location of repeaters is so selected according to the length and kind of circuit that the speech will reach the terminal in such volume that it can be heard without any difficulty. Figure 1 shows the location of telephone repeaters for the main circuits between Tokyo and Kobe.

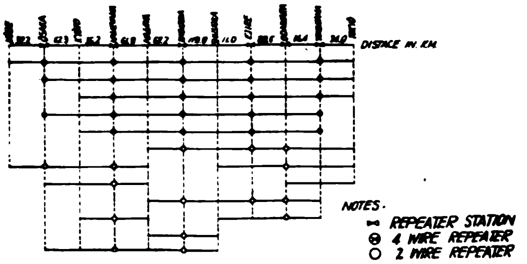


Figure 1—Layout of Toll Cable Between Tokyo and Kobe.

Cable Plan. As mentioned above in determining the number of pairs in a cable, it is necessary to take into consideration future circuit requirements. In Japan, the rate of increase of telephone lines has been very great, especially in various localities between Tokyo and Kobe; and it is thought impossible to meet all the demands for many years over ten with a single cable. Adopting the largest size allowable from the standpoint of construction and considering the status of traffic at the time of planning (1921), the number of circuits required between principal cities for the next ten years is forecast as follows:

	No. of ccts.	No. of ccts. at end of 1921
Tokyo-Osaka	54	6
Tokyo-Kyoto	6	1
Tokyo-Kobe	12	1
Tokyo-Nagoya	18	6
Tokyo-Shizuoka	12	4
Nagoya-Osaka	27	11
Nagoya-Kyoto	12	4
Nagoya-Kobe	6	0
Yokohama-Kobe	3	0
Yokohama-Osaka	6	0
Yokohama-Kyoto	3	0

In addition the number of telephone lines of shorter lengths was estimated for inclusion in the cable. It was decided to use a cable containing a total of 184 pairs of wire: 54 pairs of 1.3 mm. wire suitable for two-wire system circuits; 130 pairs of 0.9 mm. wire for four-wire system circuits and two-wire system circuits of short length. The cable is quadded, paper insulated and lead covered. (Figure 2.)

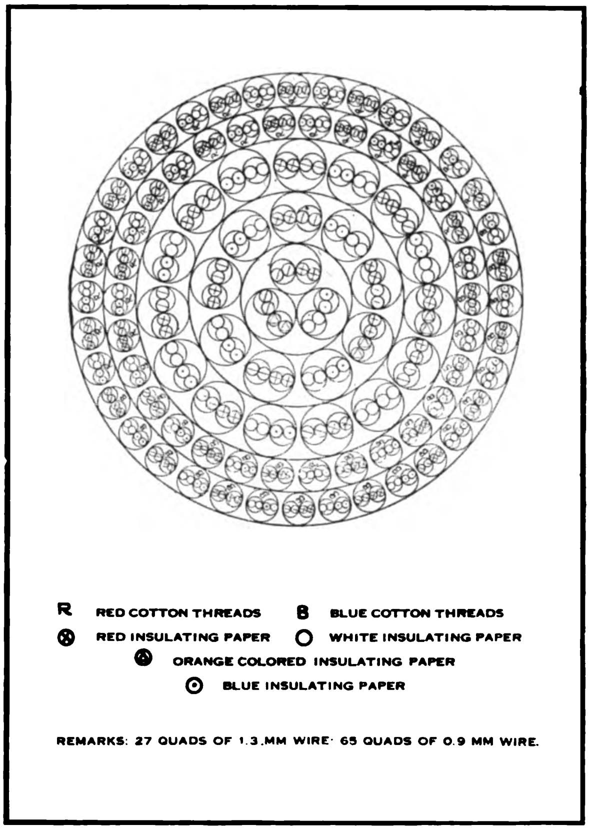


Figure 2—Cross-section of 184 Pair, Phantomed, Lead-Covered and Paper-Insulated Cable.

Loading Coil Arrangement. It is planned to equip every point of loading (i.e., each of points 1830 meters apart on the cable) with one loading coil case for 27 quads (all for two-wire system), one case for 35 quads (all for four-wire system), and one case for 30 quads (21 quads for four-wire system and 9 quads for two-wire system). The coils are designed to give the following inductance value to each conductor of a quad:

Kinds	Standard Value of Inductance Millihenrys		Remarks
	2-wire system	4-wire system	
For side cct.	177	178	Measured by A.C., 2 milliamps., 1800 cycles. Allowable limits, ±2%
For phantom cct.	107	64	

For a phantom circuit formed by each loading unit, leakage between the coils including the leads, when measured with an alternating current of 900 cycles and 2 milliamperes, is within the following limits:

Kind of Ccts.	Max. (in C.G.S. units)	Average
Between side ccts.	100	40
Between side and phantom ccts.	200	80

In the initial installation, one loading coil case for 27 quads was installed at every point of loading in each division completed, thus opening telephone traffic in the division and utilizing the completed cable as much as possible. With the completion of the cable installation between Tokyo and Kobe, loading coils for 35 quads were added, thereby opening four-wire system toll telephone traffic over lines going to Kyoto, Osaka and Kobe from Tokyo and Yokohama. When it is necessary, loading coils for 30 quads will also be added. The loading coils adopted are of the most up-to-date types used in both Europe and America with cores of compressed iron particles.[1]

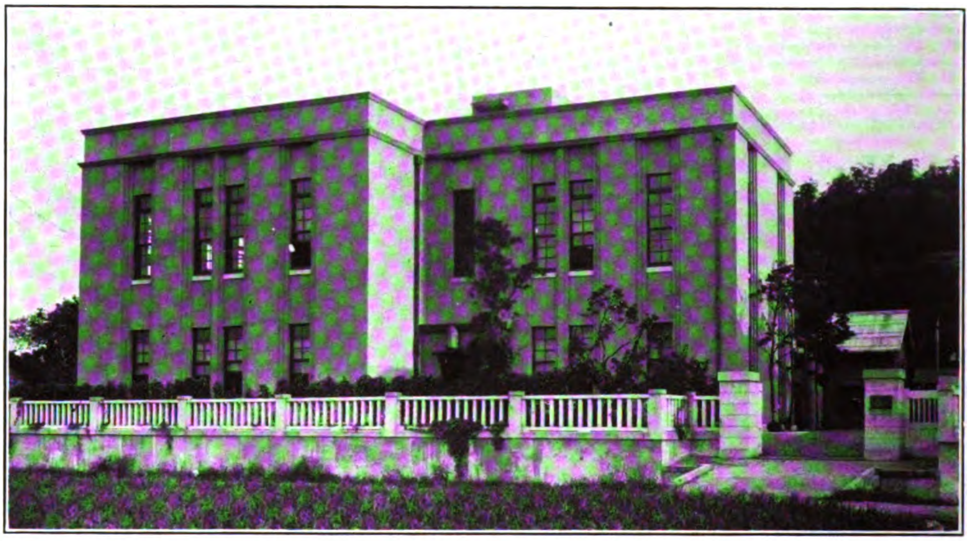


Figure 3—Repeater Station, Odawara.

Telephone Repeater Stations. The telephone repeater stations are so designed that the station buildings and the various equipment can be accommodated to the second cable line when in the future it is added between Tokyo and Osaka. Repeaters are equipped as shown by the accompanying table for the circuits needed at present, and they will be increased in number as the necessity arises.

The two-wire repeaters are of the newest type consisting of the usual vacuum tube two-way amplifier. It is provided with auxiliary equipment such as current supply circuits, alarm circuits, intermediate signaling circuits, etc., and is suitable for a gain of 19 tu[2]. A four-wire repeater is made up of two sets of amplifiers, each containing two vacuum tubes. One set is

Name of Station	Number of Repeaters 2-Wire System	Number of Repeaters 4-Wire System	Number of Repeaters Total
Yokohama	..	46	46
Ashigara	49	..	49
Yeziri	25	44	69
Toyokawa	26	44	70
Kameyama	50	44	94
Osaka	11	45	56
Total for Six Stations	161	223	384

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[1] For a description of this type of coil see paper, "Development and Application of Loading for Telephone Circuits," by Thomas Shaw and William Fondiller, Electrical Communication, Vol. IV, No. 4 and Vol. V, No. 1, 1926.

[2] R. V. L. Hartley, "The Transmission Unit," Electrical Communication, Vol. III, No. 1, 1924.

used for transmitting in one direction and the other set for transmitting in the opposite direction. Under normal conditions the repeater is suitable for a gain of 42 tu at 1,000 cycles per second. It is equipped with auxiliary current supply and alarm circuits, as is a two-wire repeater; and in the case of a terminal station where it is necessary to connect four-wire circuits directly with subscribers' circuits, terminal equipment is provided.[1]

In a telephone repeater station, power equipment and testing equipment are provided in addition to repeaters, as indicated above. The power equipment receives A.C. power from some outside source and converts it into D.C. power by means of a motor-generator set, charges a battery and supplies current to the repeaters.

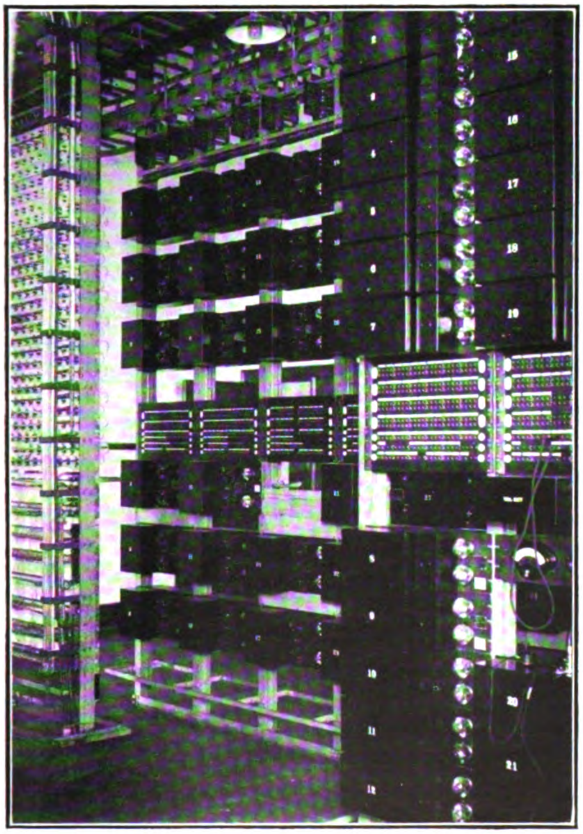

Figure 4—Repeaters, Odawara.

To provide for power failure, a spare generating equipment is installed. (Figures 3, 4 and 5).

Construction Features and Progress

There are certain advantages and disadvantages in an underground, as compared with an

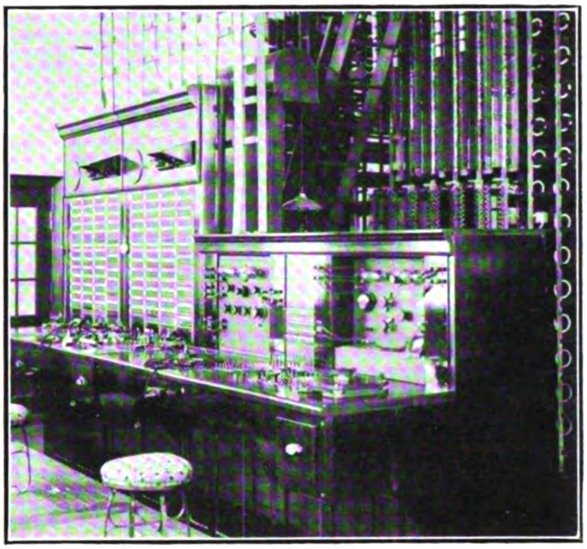

Figure 5—Repeater Station—Testing Equipment.

overhead cable line. In various countries in Europe, underground systems are generally adopted, while in America overhead systems, as a rule, are employed.

In Japan, after due consideration to the budget and the construction facilities, parts of sections where overhead construction should not result in trouble are made aerial while other parts employ underground construction. Thus, between Tokyo and Kobe about one-half of the cable line is placed over head and the other half, underground.

In order to provide for an additional aerial cable line in the future, the overhead parts of the system are constructed as follows:

Poles: Poles of 7.3 meter length impregnated with copper sulphate or creosote are used as standard. When the length exceeds 10 meters, steel towers are used.

Pole Spacing: Standard spacing is 30 meters and when it exceeds 70 meters the cable is suspended by a catenary line.

Suspension: A special steel stranded wire having a cross section of 65 square millimeters and tensile strength of 7,300 kilograms is used.

Towers for Loading Coils: Reinforced concrete construction is used chiefly, and in order to allow room for six loading coils, each tower is provided with a platform 5.5 meters by 4.5 meters. (Figures 6 to 9 inclusive.)

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[1] "Paris-Strasbourg Cable," Electrical Communication, Vol. VI, No. 1, 1927.

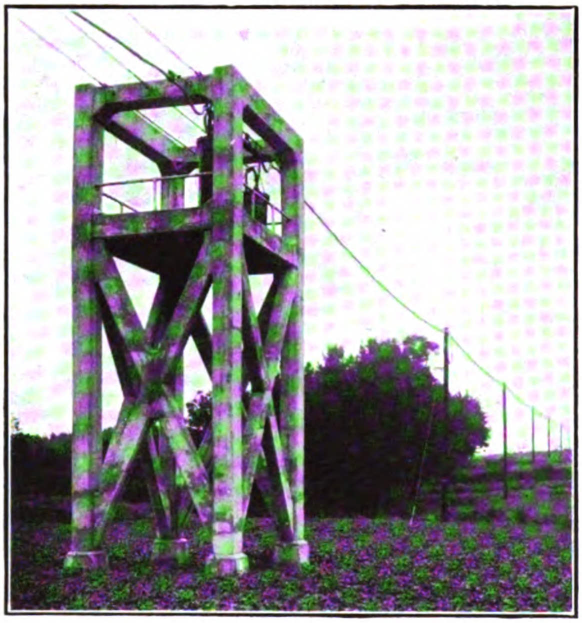


Figure 6—Reinforced Concrete Aerial Cable and Loading Coil Platform.

The underground system is constructed as follows:

A line of cast iron pipes, each having an internal diameter of 75 millimeters, is buried in places where the water line is near the surface of the earth, and in other places two-holed earthen conduits or two-holed concrete conduits are used. In case cast iron pipes are used under a paved road or in other places where access is difficult, a spare pipe line is installed. Where roads are much curved or where conduits cannot be advantageously installed, armored cables are used.

Manholes are constructed either of reinforced concrete or of bricks, and provisions are made to prevent water from entering them. In manholes, where it is necessary to place loading coils, provision is made, corresponding to the overhead line procedure, to install six in one hole by constructing it 2.6 meters long, 1.8 meters wide and 3 meters deep, internal dimensions. Manholes located in places where it is required to test the cable are constructed to internal dimensions of 1.8 meters long, 1.2 meters wide and 1.3 meters deep. Manholes in other places are constructed to smaller dimensions.

In places where the cable crosses rivers, a field investigation was made in each case to determine whether overhead or underground construction should be adopted. In some cases, steel towers were put up on both banks and in rivers, suspending the cable from catenary lines; and in other cases, special bridges for the cable were constructed, or the cable was strung along existing bridges. (Figures 10, 11, and 12.)

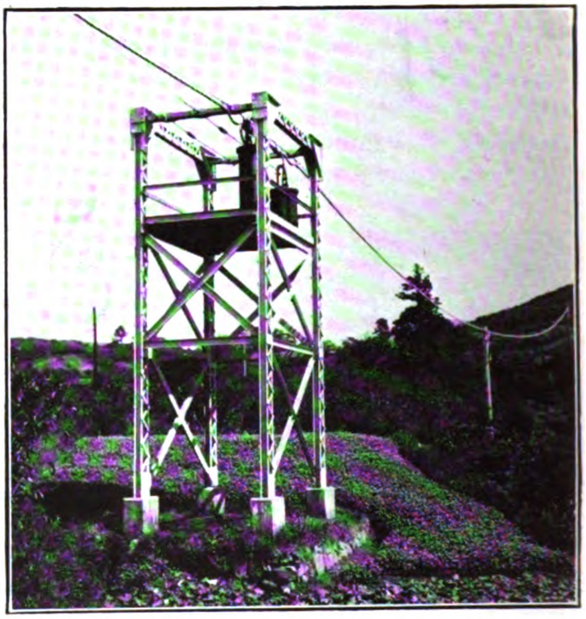


Figure 7—Structural Steel Loading Coil Platform.

Progress of Installation Work

It was initially planned to complete the construction work between Tokyo and Odawara in 1923; between Odawara and Shizuoka and between Nagoya and Kyoto in 1924; between Shizuoka and Hamamatsu and between Kyoto and Osaka in 1925; between Hamamatsu and Nagoya in 1926, and between Osaka and Kobe in 1927, thus completing a route from Tokyo to Kobe. Owing however, to the Kanto Earthquake of September, 1923, the start of work in Tokyo Teishin District was delayed. As a consequence, a part of the cables, loading coils, etc., which was purchased for the Tokyo-Odawara division and which had not been used, was installed between Nagoya and Kyoto. Traffic was thus, at first, opened in the Nagoya-Kyoto-Osaka division. Other minor changes were made in the construction schedule. Work was completed as shown in the table given below, the route between Tokyo and Kobe being finished on November 1, 1928.

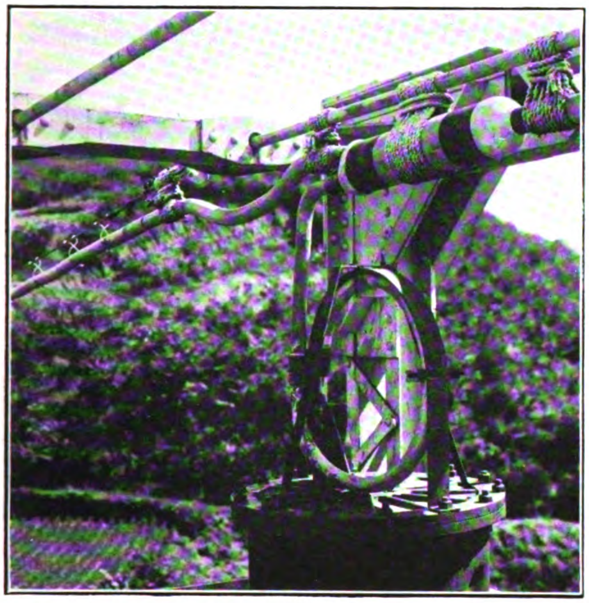


Figure 8—Cable Joint, Coil and Stub, on Loading Coil Platform.

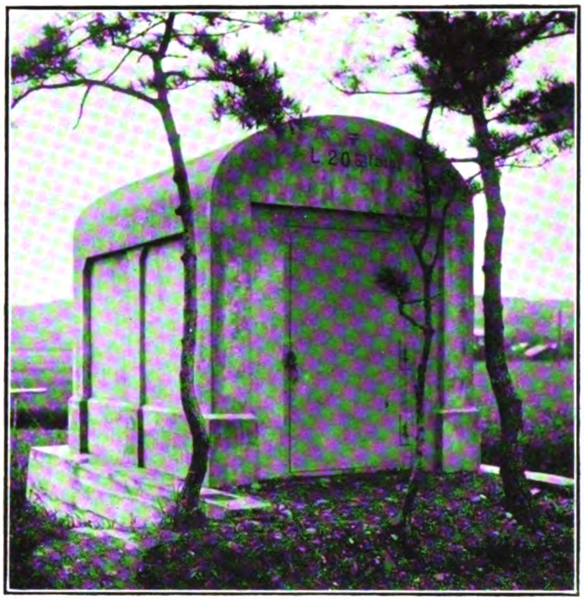


Figure 9—Reinforced Concrete Loading Coil Hut.

In general, the cable route is selected for laying along highways; but in parallel with the latter are the telegraph, telephone, light and power lines of bare overhead construction, or railways of the Teishinsho, Government Railway Department, prefectures, or private companies. In addition, the route has the sea on one side and mountains on the other, and in some places it crosses large rivers. In view of this situation, the cable had to be laid in safe zones separated a reasonable distance from the obstacles mentioned, with each loading point spaced exactly at 1830 meters. Accordingly, in selecting the route, a careful survey was made for alternative routes. Many changes in routes were made, owing to reconstruction of highways or bridges or the building of a house. In each case, the route between two repeater stations had to be

Division	Length, Kilometers			Date of Completion	Remarks
	Underground	Aerial	Total		
Tokyo-Yokohama . . .	34.0	. .	34.0	Sept. 11, 1927	Yokohama Repeat. Sta. opened for traffic on Sept. 11, 1928
Yokohama-Ashigara	32.0	24.4	56.4	Nov. 21, 1926	Ashigara Repeat. Sta. opened for traffic on Nov. 21, 1926
Ashigara-Numazu . . .	9.9	28.7	38.6	Sept. 11, 1927	
Numazu-Shizuoka . . .	30.0	30.9	60.9	Nov. 16, 1927	Yeziri Repeat. Sta. opened for traffic on Sept. 15, 1928
Shizuoka-Mitsuke . . .	31.0	35.5	66.5	Oct. 6, 1928	
Mitsuke-Toyokawa . .	14.6	38.7	53.3	July 1, 1927	Toyokawa Repeat. Sta. opened for traffic on July 1, 1927
Toyokawa-Nagoya . .	23.9	43.3	67.2	June 16, 1927	
Nagoya-Kameyama. .	16.2	45.6	61.8	Aug. 16, 1925	Kameyama Repeat. Sta. opened for traffic on Aug. 16, 1925
Kameyama-Kyoto . . .	56.6	29.6	86.2	Aug. 16, 1925	
Kyoto-Osaka	52.3	. .	52.3	Oct. 30, 1926	Osaka Repeat. Sta. opened for traffic Nov. 1, 1928
Osaka-Kobe	32.2	. .	32.2	Nov. 1, 1928	
Total	332.7	276.7	609.4		

re-surveyed because of the necessity for maintaining proper spacing for the loading coils. The decision was finally made to lay the cable as follows:

Tokyo-Yokohama Section: Underground system. The cable was laid in the national highway before it was reconstructed last.

Yokohama-Odawara Section: Partly underground in the national highway and partly overhead along it.

Odawara-Numazu Section: Since neither the old nor the new national highway in the Hakone is suitable for an underground system, the section between Hakone-Yumoto and Ashino-yu is mostly of overhead construction through Takanosu Pass; and the rest also is mostly of overhead construction, generally along the national highway.

Numazu-Shizuoka Section: The cable between Numazu and Suzukawa is mostly hung overhead along the railway; between Suzukawa and Yui it is buried underground in the national highway; between Yui and Okitsu it passes aerially over Sassui Pass; and thence, it is run to Shizuoka mostly along the national highway, partly underground and partly aerial.

Shizuoka-Tenryukawa Section: Partly underground and partly overhead along it.

Tenryukawa-Miyu Section: As it is difficult to cross Lake Hamana, the cable is laid partly underground in a prefectural highway called Old Hime-Kaido and partly overhead along it, across Honsaka Pass.

Miyu-Nagoya Section: Mostly overhead along national highway between Miyu and Okazaki, and the prefectural highway through Tenpaku between Okazaki and Nagoya; underground from city limit of Nagoya to Nagoya Station.

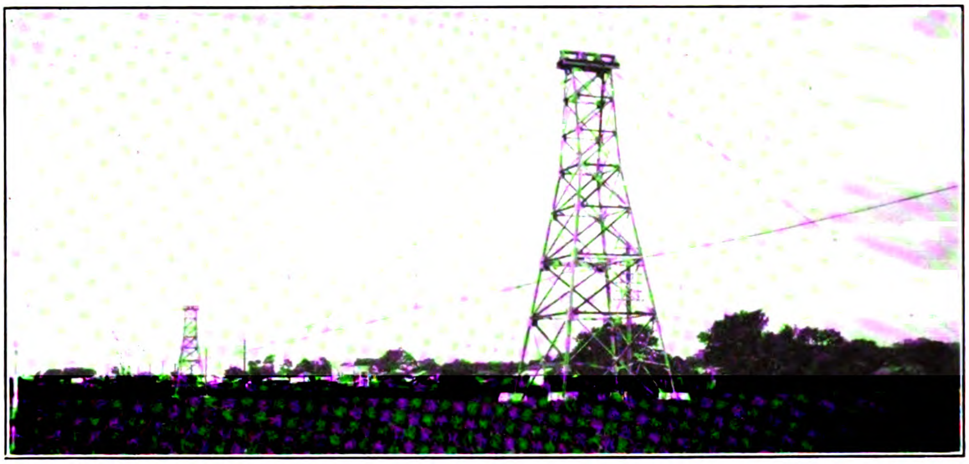


Figure 10—Steel Tower for Cable Crossing the Sakai River near Hakone.

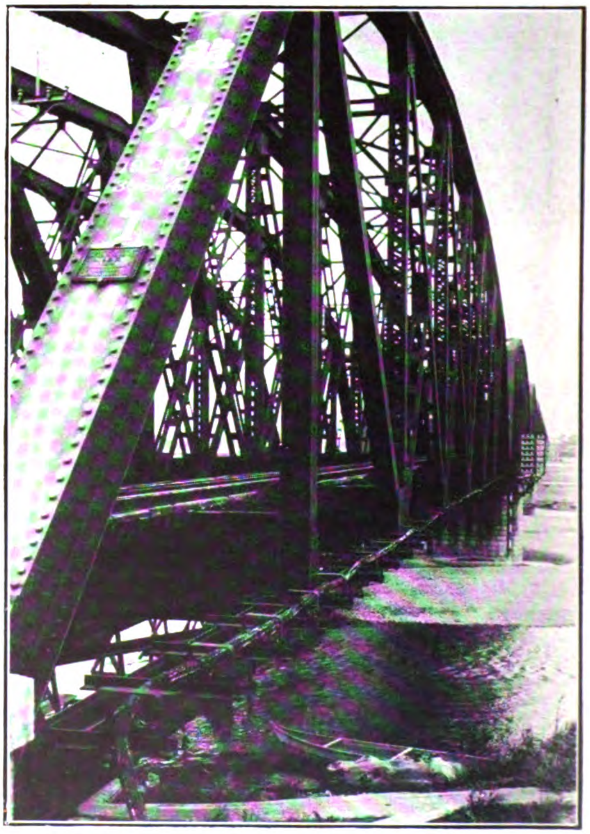


Figure 11—Armoured Cable Placed on Railroad Bridge Across the Tenryu River.

Nagoya-Kyoto Section: Underground within the city limit of Nagoya, and thence overhead to Seki, along the Kansai railway line; overhead along the national highway from Seki to Kusatsu through Suzuka Pass; except over the Pass where an armored cable is used; underground from Kusatsu to Kyoto.

Kyoto-Osaka Section: All underground in a prefectural highway called Old Saikoku Kaido.

Osaka-Kobe Section: All underground in the national highway lately reconstructed.

Many dangers and difficulties were encountered in the transportation and installation of the cables and loading coils inasmuch as the cable route traversed high and steep mountain paths such as Hakone, Housaka and Suzuka, and large rivers such as Akagawa, Fujikawa, Oikawa, Tenryukawa, Kisogawa, Ibigawa, Setagawa, and Yodogawa. Fortunately, the work has been completed without any serious accident.

Supply of Principal Materials

Cable.—As previously mentioned, the cable adopted is suitable for phantom working and consequently differs from suburban toll cable heretofore used in Japan for short distances, such as between subscribers in the same city or within the city boundary for lines incoming to a city. Since home manufacturers had no experience in the manufacture of the type of cable required, the part employed between Tokyo and Odawara and also between Nagoya and Osaka, totaling approximately 98,500 meters, was supplied by the Western Electric Company, U.S.A. It was found afterward, however, that the Sumitomo Electric Wire and Cable Works, Ltd., the allied Cable Company of the Nippon Electric Company, Ltd., and others, after careful researches into the method of cable manufacture, could produce cables which were not inferior to those imported. Consequently, the cable of home manufacture was adopted for the entire remaining parts, totaling 542,400 meters.

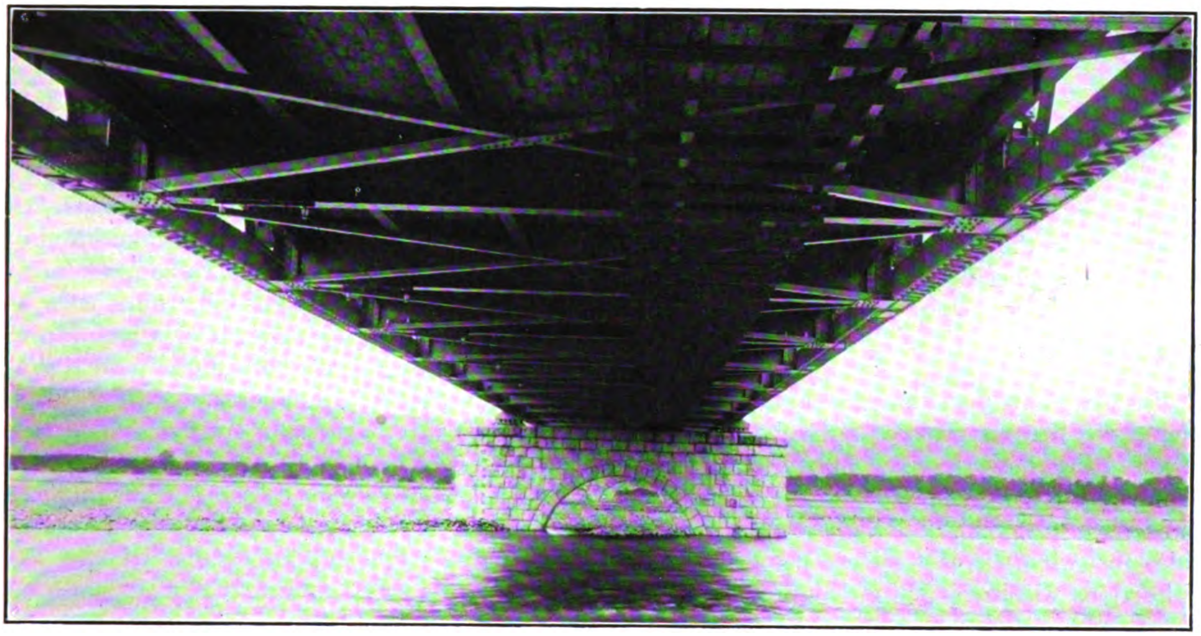


Figure 12—Toll Cable Placed Under Bridge—Oi River.

Loading Coils.—The first loading coils used were imported. Subsequently, however, the Nippon Electric Company, Limited, Tokyo, has been producing coils not greatly different from those made in the United States of America, and, they have since been purchased along with the imported product.

Between Tokyo and Kobe, 698 cases of loading coils were used. It is planned to install loading coils for 30-quad use between Tokyo and Osaka in the fiscal year of 1929.

Telephone Repeaters.—As no home manufacturer had had experience in the manufacture of telephone repeaters, all the apparatus and materials installed initially at Kameyama Repeater Station were supplied by the Western Electric Company, through the Nippon Electric Company. In subsequent installations, however, only apparatus and materials which could not be manufactured in Japan were imported. In the other cases, articles made in Japan were adopted.

Miscellaneous.—Such materials as cable hangers, used in suspending the aerial portions of the cable, hanger connectors and cable rings, estimated to be required between Tokyo and Shizuoka, were imported. Subsequently, trial supplies were ordered from home makers and, inasmuch as they proved satisfactory, the home product has since been used exclusively.

Future Plans

In view of the fact that the cable just opened for traffic between Tokyo and Kobe will, in the near future, have no spare lines because of the demand for toll telephone circuits, it is planned to install a second cable. There is a necessity also for extending the present cable in various directions within ten years (Figure 13). In the direction of the southwest it will be extended from Kobe via Okayama and Hiroshima to Shimonoseki and thence to Fukuoka and Kumamoto across the strait, branching out to Nagasaki. In this division traffic is expected to be opened in 1929 between Kobe and Okayama and also betwen Moji and Fukuoka; in 1927 traffic was opened between Fukuoka and Kurume. In the direction of the northeast the cable will be extended from Tokyo via Utsunomiya and Sendai to Aomori, thence across the strait to Hakodate, and via Odaru and Sapporo to Asahigawa. The cable between Tokyo and Koyama was scheduled for completion in 1928: the cable between Koyama and Utsunomiya, also between Odaru and Sapporo, for completion in 1929. The extension between Aomori and Hakodate was completed in 1926 by the connection of the land and submarine cables. In addition, most of the divisions considered as toll trunks, such as those from Tokyo to Matsumoto via Kofu, from Nagoya to Toyama via Gifu, Fukui and Kanazawa, from Kyoto to Fukuchiyama, from Osaka to Tanabe via Wakayama, and from Okayama to Takamatsu, will be changed over from the existing bare wire lines to cables, thus insuring safety and smoothness in telephone conversations between the all important cities of the country.

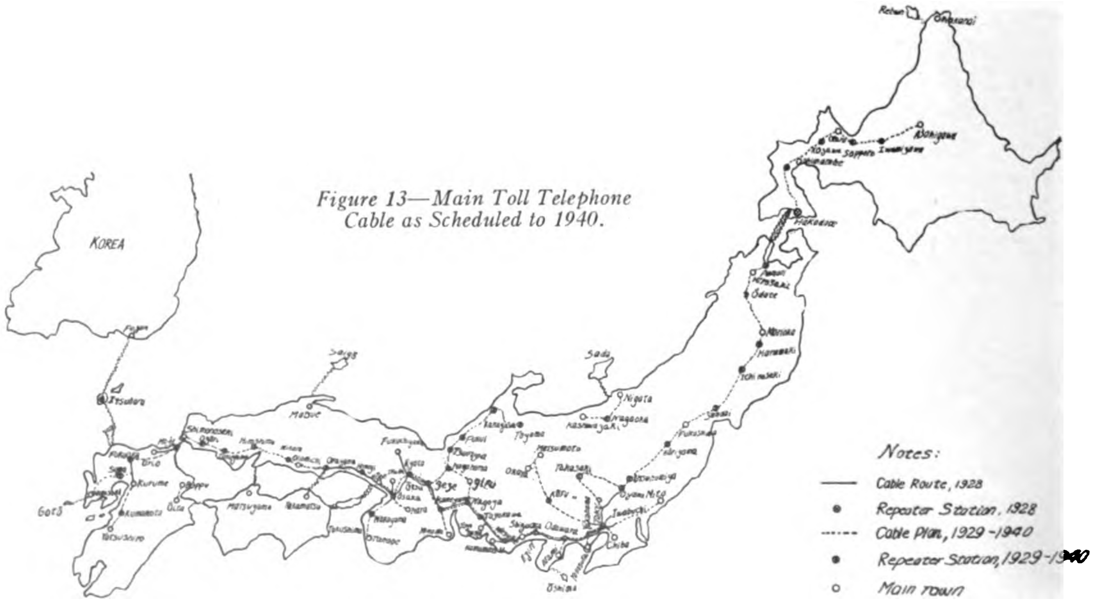


Figure 13—Main Toll Telephone Cable as Scheduled to 1940.

South American Transcontinental Telephone Circuits Connecting Argentina, Uruguay and Chile.

By F. A. HUBBARD

Assistant Chief Engineer, International Telephone and Telegraph Corporation

DURING the year 1927 the International Telephone and Telegraph Corporation acquired control of telephone properties in Argentina, Uruguay, and Chile. It obviously was desirable to provide long distance telephone service between these territories as early as possible. But natural barriers,—the Rio de la Plata in the one case, and the Andes in the other,—made the construction of such long distance lines a matter of considerable time and expense. It so happened, however, that All America Cables, Inc., another operating company of the International System, already had wires inter-connecting Buenos Aires, Montevideo and Santiago for telegraph purposes; and it was decided to investigate the possibility of superposing telephone service on these wires. These lines form part of the Company's main cable route to Buenos Aires, Rio de Janeiro and other points on the east coast of South America.

The layout of the circuit is indicated in Figure 1. Study of it showed that there were two sections that were particularly unsuited for telephone purposes,—the river cables under the Rio de la Plata, and the mountain section, particularly the 40 miles of single-conductor rubber-covered cables. A third very unpromising stretch, the entrance to Buenos Aires, was avoided by the use of Telephone Company wires, as indicated in the sketch. From Rio Blanco to Santiago a separate pair of copper wires was strung on the All America poles, thus avoiding the complica-

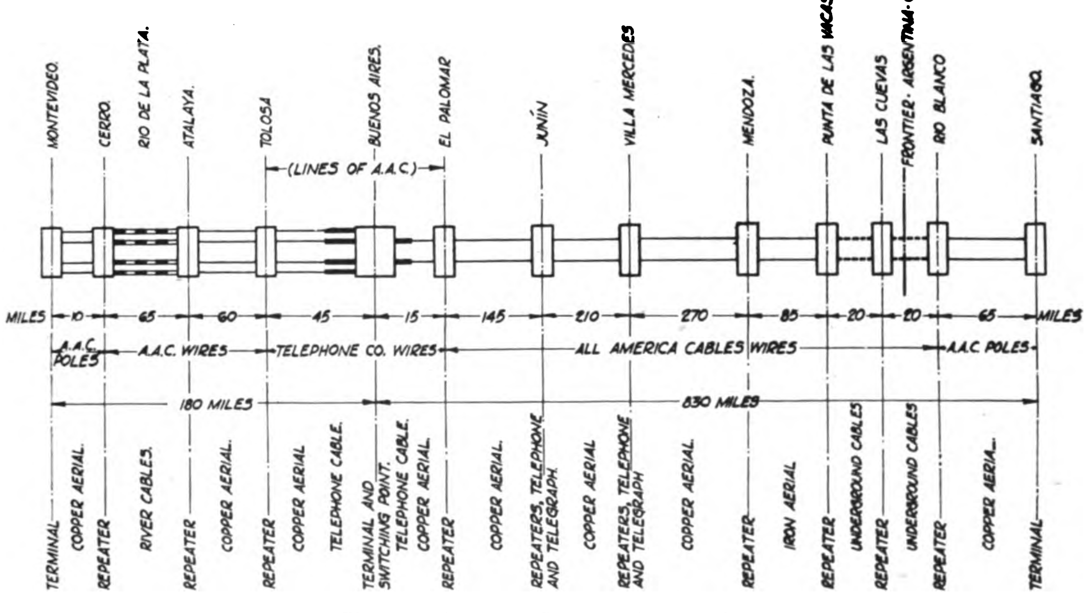


Figure 1—Layout of Transcontinental Line.

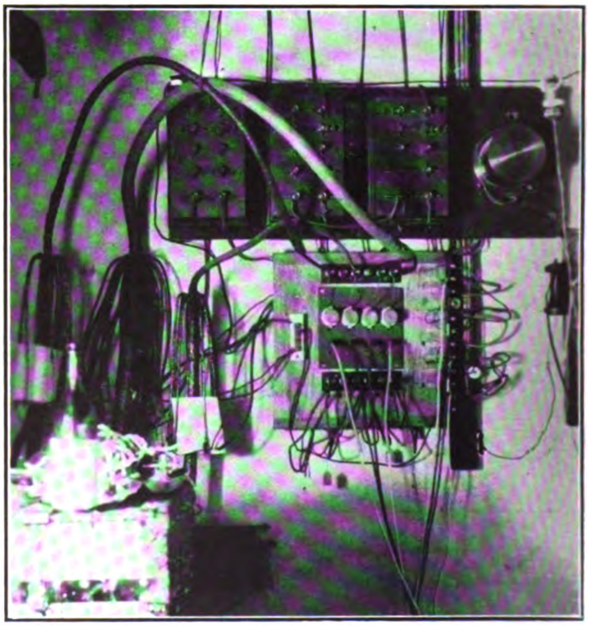
tion of a telegraph repeater station 20 miles from the former. For the rest, except for the short stretch from Montevideo to the cable hut, the main wires of the cable company were used.

During the latter part of the year 1927 a certain amount of preliminary work was accomplished, particularly the transposition of the major part of the main line, and the assembly of certain repeater and composite equipment at Buenos Aires. It was not, however, until the middle of January, 1928, that it was possible to make a definite beginning. Since the Buenos Aires-Montevideo connection was of the first importance, and since the technical difficulties presented by the more than 65 miles of river cables,—inaccessible, of course, except at the ends,—promised to be the most severe, the most intensive part of the laboratory study was concentrated there.

Cerro Cable Hut—Rawlings, Hubbard and King.

Comparatively little work has been done on the characteristics of such cables at telephone frequencies, though some studies were made in connection with the preliminary stages of the design of the Key West-Havana telephone cables. This was described in a paper presented before the American Institute of Electrical Engineers on February 15, 1922, by Messrs. Martin, Anderegg, and Kendall, and in a mathematical study by Messrs. Carson and Gilbert, published in December, 1921, in the Journal of the Franklin Institute. The most significant fact brought out by these studies was the rapid increase in effective resistance of the sea return path with increase in frequency. This was shown to be due to a "crowding in" of the return currents around the core of the cable, which was found to force these currents into the steel armor wires and into a relatively very small cross-section of water immediately around the cable itself. It will be remembered that in view of this the Key West-Havana cables were provided with a heavy copper tape in contact with the sea water, and that the sea return resistance proved to be substantially equal to the resistance of this tape for frequencies above about 500 cycles. By the provision of this return conductor, and the addition of inductance by means of a layer of iron wire, excellent telephone circuits were produced. Naturally neither of these expedients could be applied in this case, since the cables had to be used as they were.

As indicated in the sketch, there were four cable conductors, of which two (known as No. 3 and No. 4) made up a bi-core cable, being armored together. These conductors weighed 250 lbs. to the nautical mile (about 3 millimeter



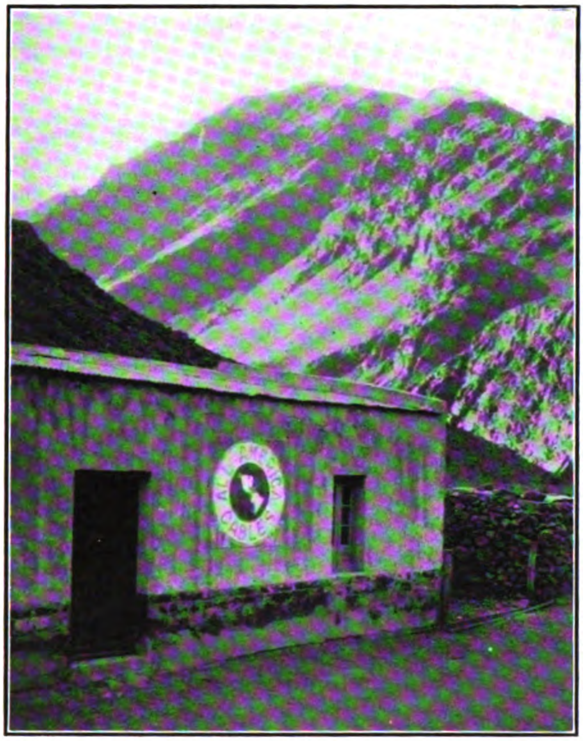
Cerro Hut Interior—Termination of River Cables.

diameter, equivalent to between No. 8 and No. 9 AWG). The capacity of each conductor to ground was in the vicinity of 0.31 microfarad per nautical mile. One of the other cables (No. 2) was approximately the same as Nos. 3 and 4, but was in an individual sheath. The other cable (No. 1) had a 600-lb. conductor, about 4.6 millimeter, No. 5 AWG. This cable had a somewhat higher capacity in the neighborhood of 0.35 microfarad per nautical mile. All the cables were provided with a thin brass tape for protection against the teredo.

The simplest solution seemed to be the use of the four conductors to form a 4-wire circuit of the ordinary type. Such a circuit would require some investigation, since no data were available on the characteristics of a metallic loop comprised of two entirely separate cables; and there might be expected some difficulties from telegraph noise, or interference with the telegraph circuits. These complications were vastly increased, however, and the simple 4-wire circuit entirely ruled out, by a decision that, if possible, two separate circuits should be provided, instead of one. The reason for this decision was the expectation that in view of the great community of interest between Buenos Aires and Montevideo, and the poor communications previously available between them, the opening of a good service would result in a volume of traffic that would speedily congest a single circuit. That this expectation was justified is shown by the fact that within six months after the opening of the service it was handling on the average more than 50 calls per working day,—a fair load for two circuits.

It was necessary, therefore, to evolve two circuits from the four conductors described. At the same time speed was of cardinal importance. It was desired to open the whole system, including the line to Chile, before the middle of the year. Many interesting investigations on the cable characteristics, therefore, had to be abandoned, and the studies limited to absolutely essential measurements and to the design and construction of amplifiers and equalizers which, if possible, should make the cables usable for telephone purpose.

The first experimental work involved determining the attenuation characteristics of all the possible combinations of cable conductors, in order to show which indicated the most promise. The attenuation of each conductor was measured with ground return, and all the possible combinations of metallic circuits were tried. The first method used was the well-known one of the open and short-circuited impedance. This proved very useful at the low frequencies but beyond 600 cycles it was valueless because the differences became extremely small. The curves were therefore extended by means of straightaway current measurements with thermocouples at the two ends, using a calibrated amplifier on the receiving end when the loss became too great for direct thermocouple measurement. The various methods showed a sufficiently close agreement for the necessities of the case.



Lineman's House and Repeater Station at Punta de Las Vacas—7,500 feet elevation.

The only one of the combinations that showed any immediate promise was the bi-core, used as a metallic circuit, and even this was none too encouraging. The bare line attenuation at 1,000 cycles was 29 decibels. This was sufficiently high, but it was considerably lower than any of the others. Also, it lacked the characteristic steep slope that all the other combinations showed, the attenuation at 2,000 cycles being only 34 db. The attenuation curve is shown in Figure 2: it resembles in shape that of an ordinary non-loaded paper-covered cable, although it was somewhat steeper, due probably to dissipation in the dielectric.

It was decided, therefore, to try a 2-wire circuit on this pair of conductors, equalizing as nearly as possible at 2,000 cycles. Fortunately, the impedance characteristic proved to be very smooth; and though the design of networks to match it presented some difficulties, on account of a reactive component decreasing with frequency, an excellent singing point was finally obtained. In fact, more trouble was experienced with the balance of the composite sets, which had to be adjusted carefully to permit advantage to be taken of the accuracy of the basic networks.

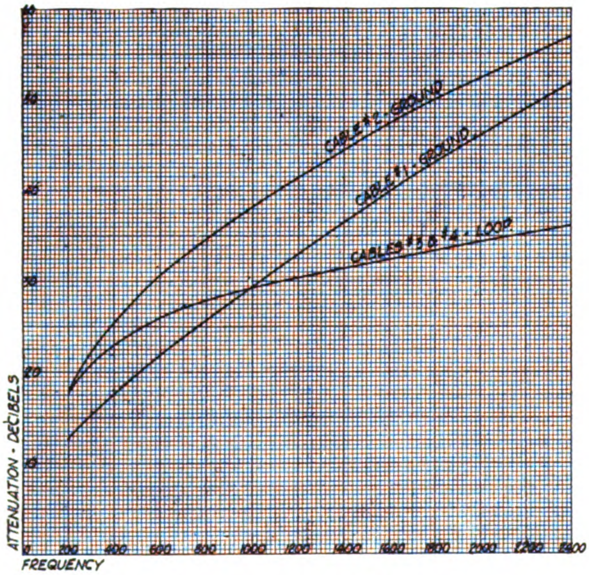


Figure 2—Attenuation of River Cables.

In order to set up a commercial circuit over this line, it was necessary to provide more gain at the ends than could be obtained from the ordinary repeaters that were available. They were therefore rebuilt to introduce a second stage on the receiving side. The possible gain when transmitting into the cable was of course limited by overloading considerations, particularly at the Montevideo end, which was only about 10 miles from the city. A total gain in each direction of about 40 db was obtained, so that the attenuation of the cable was somewhat more than offset; and the overall circuit loss between Montevideo and Buenos Aires finally proved to be about 12 db.

One satisfactory circuit being thus assured between these points, work was commenced on the line to Chile. With the necessity for an early opening of the system, and with the approach of winter, it was obviously impossible to undertake any experimental work in the mountains as had been hoped. Under these circumstances it was decided to select repeater stations arbitrarily, on the basis of estimates of probable attenuation, and to hope for the best. No great amount of actual traffic was anticipated between Chile and Buenos Aires.

Accordingly, repeaters were placed at the two ends of the cable section, which, as has been mentioned, was forty miles long, and at its middle. Fortunately, linemen's houses were located at each of these points. Others were placed as indicated in Figure 1. A great deal of trouble was anticipated with the use of the single conductor cables, since in some cases the two sides of the circuit would not even be near each other, but followed different routes,—the idea in so installing them being, of course, to provide for maximum safety against avalanches. This arrangement appeared likely to make the balancing problem extremely difficult, and to cause serious inductive interference from other telegraph circuits in the vicinity and from the electrification of the Transandine Railway on the Chilean side.

If these problems had assumed the proportions that seemed entirely likely, the whole job would have had to wait until an intensive experimental study could be made, and the layout accordingly revised. Fortunately, however,—perhaps as a compensation for some other difficulties that arose in places where they were least expected,—the tentative layout worked reasonably well from the first, and was never changed. The impedance characteristics of the peculiar cable circuits proved to be fairly smooth, and empirical networks, designed and constructed on the spot, permitted gains of 12 or 14 db at each repeater. A certain amount of power hum was noticeable, but not enough to be serious. The linemen's houses, especially the one at Las Cuevas, 10,000 feet above sea level, were not especially commodious as repeater stations, with the batteries and charging engines to be accommodated; but on the whole they did very well.

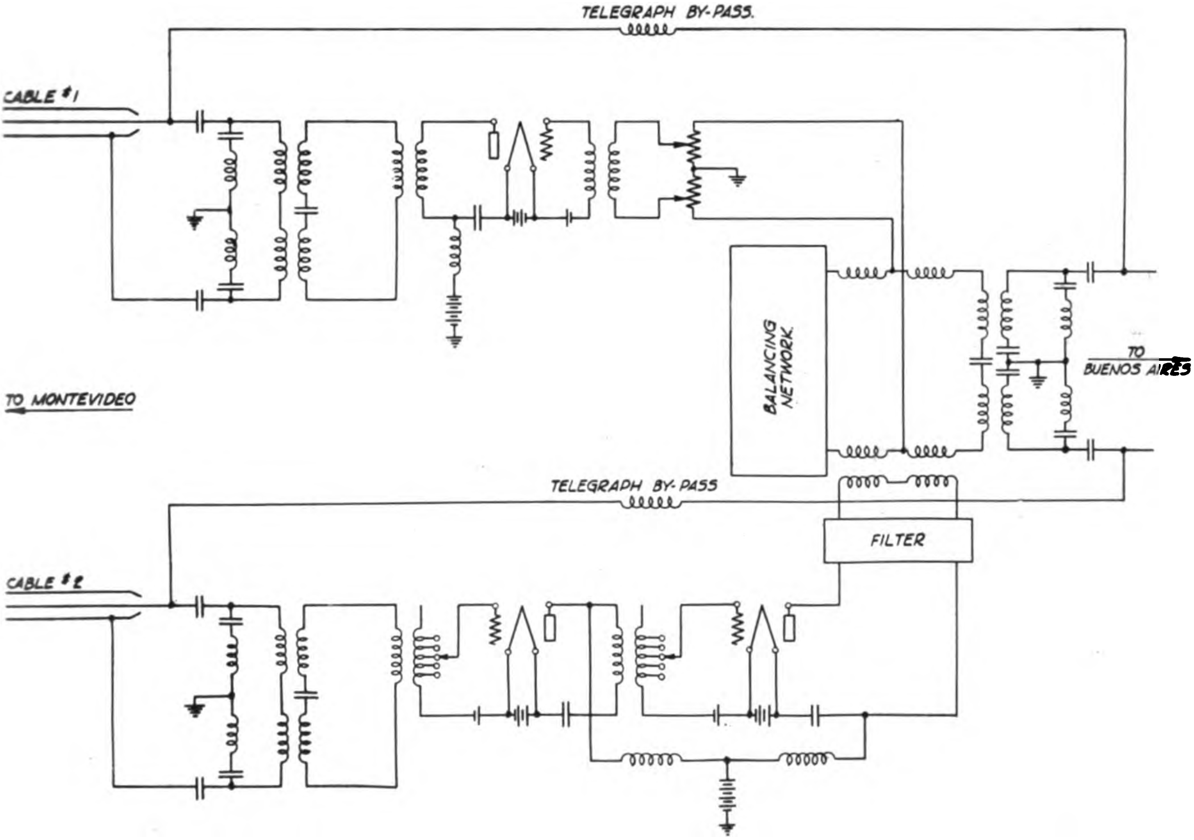


Figure 3—Schematic of 4-Wire Repeater at Atalaya.

Meantime, work was resumed on the second circuit on the river cables. The metallic loop between the two remaining cables, No. 1 and No. 2, showed an attenuation of about 35 db at 1,000 cycles, which climbed steeply to over 50 db at 2,000 cycles. It is not entirely clear why the attenuation curve of this metallic circuit showed such a steep slope, substantially parallel to that of circuits with ground return. It had been hoped that the avoidance of the "crowding-in effect," together with the influence of the inductance of the loop,—since the sides of the circuit were at a distance from each other,—might result in a more favorable characteristic.

The only alternative was some form of 4-wire system, using separate lines for talking in the two directions, since in such a system the gain is not limited by conditions of balance. In this case, however, as only two conductors were available, it would be necessary to use ground return in each direction. It seemed improbable that such a system would work, because the common ground return would constitute a coupling between the incoming and outgoing sides of the circuit; and as these would be at a difference in level of over 50 db, it seemed likely that this coupling would be sufficient to establish a singing circuit through the repeaters. Still, it was hoped that the crowding-in effect, which increases so greatly the attenuation, might operate to advantage in this case by confining the return currents so closely to the sheaths of their respective cables as to prevent them from interfering with each other.

Accordingly such a circuit was made up, using cable No. 2 and its sheath for transmission from

Montevideo to Buenos Aires, and cable No. 1 and its sheath for transmission in the reverse direction. The sheath of the bi-core cable was left connected to the office grounds at the two ends, to which all the sheaths had been connected; and thus probably served as the principal return path for the telegraph currents. A simplified schematic of the repeater and composite set at one end of this unique circuit is shown in Figure 3; and the characteristics of the two cables are included in Figure 2.

The hoped-for effect actually took place. In spite of the fact that at the Argentine end the cables lay together in a trench for a quarter of a mile or more before reaching the water and separating, it was found possible to use a receiving gain of about 45 db, and a transmitting gain of about 12, without any signs of singing. The gains required at the Montevideo end were somewhat less, as the attenuation of the No. 1 cable was about 7 db less than that of No. 2, being about 46 db at 2,000 cycles, against 53 for No. 2. The gains available were thus more than sufficient to cancel the loss in the cables and composite set, giving a circuit only slightly inferior to the one first obtained on the bi-core cable.

Considerable trouble was experienced with telegraph interference from the Rio cable, which had a telegraph repeater at Atalaya, and which lay close to the Montevideo cables as far as the river. Since this was a long-distance cable, it was not possible to apply to it the noise-killing apparatus that was so effective on the other lines. It was found, however, that with the aid of the sea earth,—an auxiliary conductor armored with the main conductor, and grounded some 15 miles from shore,—the interference was entirely eliminated. The only remaining trouble was a slight amount of static noise during thunderstorms.

This was almost the only case in which severe telegraph interference was experienced. The compositing equipment, of ordinary types, eliminated most of it; and additional noise-killers, comprising retardation coils and condensers in the telegraph transmitters, took care of the rest, but they were not required in every case. There was some effect from the composite sets upon the duplex balance and the quality of the recorder signals, and certain precautions had to be taken to avoid cross-fire between the two sides of the circuit.

While the second river circuit was being worked out, the land-line repeater stations had been put in order; and on June 22, five months after starting the experimental work, the complete system was formally opened for commercial service.

Mount Tolosa with the Glaciers—Near the Head of the Pass Over the Andes.

Phase Compensation (I)
A Simple Account of Phase Compensation

By E. K. SANDEMAN

European Engineering Department, International Standard Electric Corporation

THE literature of phase compensation gives the impression that intricate mathematical processes are unavoidable in order to achieve a proper understanding of the subject. Further, there is conveyed an entirely erroneous idea of the fundamental difficulties, which actually are not very great. In practice, difficulties begin to become apparent only when special circuits are employed to reduce the total amount of apparatus required. It is therefore felt that no excuse is necessary for presenting, at this stage, a simple account of the what, why, and how of phase compensation, which will be easily comprehensible to anyone possessing an elementary knowledge of transmission theory. For simplicity, in this discussion, it will be assumed that all steady frequencies are transmitted with the same efficiency.

In an ordinary transmission line possessing the constants R, G, L, and C per unit length, the propagation constant is given by

$$p = \beta + j\alpha = \sqrt{(R + j\omega L)\ (G + j\omega C)}$$

Under steady state conditions the current at any point in the line distant l from any chosen reference point is given by

$$I = I_0 e^{-(\beta + j\alpha)l} = I_0 e^{-\beta l - j\alpha l} = I_0 e^{-\beta l} \ \overline{\backslash \alpha l}$$

where I_0 is a vector representing a sinusoidal current at the reference point. The phase of the current along the line, therefore, changes by the angle α per unit length, and if a length of line λ is chosen such that the phase change along it is 2π, i.e., so that $\lambda = 2\pi$, then one complete rotation of phase has taken place, or alternatively the length of line λ contains a wave length, i.e.,

$$\lambda = \frac{2\pi}{\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Every time the current at the reference point passes through a complete cycle, which takes place f times a second, where f is the frequency, a complete wave length is launched on the transmission line. There are therefore f such wave lengths launched per second, so that each wave travels forward with the velocity:

$$V = \lambda f = \frac{2\pi f}{\alpha} = \frac{\omega}{\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The velocity V defined by equation (2) gives the rate of travel of a wave crest which is part of an infinite sinusoidal wave train, whereas the telephone engineer is concerned only with the rate of travel of finite wave trains. As an example of a finite wave train any part of an ordinary speech wave may be taken.

From the principles developed by Fourier it is possible to consider a finite wave train as being made up of an infinite number of infinite sinusoidal wave trains which for all time and space have a zero resultant, except at the time and place where the finite wave train exists. The wave crests of the infinite wave trains travel with the velocity V as defined by equation (2).

In general the finite wave train does not move with the velocity V and no one velocity can be assigned to it, since, as it moves it expands or contracts along its direction of travel. The position of the finite wave train at any instant is evidently defined by the envelope of the infinite wave trains composing it. By taking the infinite wave trains in pairs contiguous in the frequency range, and considering the rate of travel of their envelopes, it is possible to arrive at a very close idea of the behaviour of any finite wave train travelling through a medium of known characteristics.

Group Velocity. In Figure 1, 1, 2, 3, etc., are the crests of an infinite sinusoidal wave train of wave length λ travelling at velocity V from the left towards the right, and a, b, c, etc., are the crests of another infinite wave train contiguous in the frequency range. If the two infinite wave trains are considered to be part of a finite wave train, not shown, then their frequencies, and so their wave lengths, will differ only by an infinitesimal amount. The wave train a, b, c may therefore consistently be considered to be of wave length $\lambda+d\lambda$ and to travel at a velocity $V+dV$ from left to right. By simple addition of the amplitudes of the two wave trains the full line curve at B is obtained, an infinite wave train whose amplitude varies periodically from maximum to minimum and vice versa. Thus an infinite train of finite wave groups becomes discernible, each identified by an indefinitely repeated envelope, indicated by the dotted line. The physicist is accustomed to consider the individual wave crests as being the essential entity, rather than the envelope; hence, group velocity[1] has been used for the rate of travel of such a wave system. It probably will be easier to keep in mind the idea of *envelope velocity* while using *group velocity* to mean the same thing in order to be consistent with classical theory.

The highest crest in the resultant group in Figure 1 (the crest at the middle of the group) is coincident with the two wave crests 4 and d, which are in phase with each other. The velocity of crests a, b, c, etc., *relative* to crests 1, 2, 3, etc., is dV. The time taken for crest c to overtake crest 3 is $\frac{d\lambda}{dV}$ and, when crests c and 3 become coincident the centre of the group will travel the distance λ backwards relative to crests 1, 2, 3, etc. Consequently the velocity of the group relative to crests 1, 2, 3, etc., is

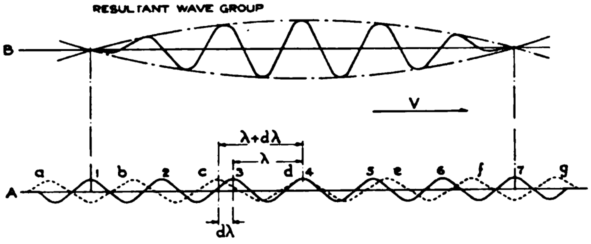


Figure 1—Wave Group.

$$-\frac{\lambda}{\frac{d\lambda}{dV}} \quad \text{or} -\lambda\frac{dV}{d\lambda}$$

and therefore the velocity γ of the group is,

$$\gamma = V - \lambda\frac{dV}{d\lambda}$$

The above proof will be found in Franklin and Termans' "Transmission Line Theory."

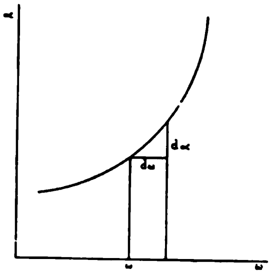


Figure 2—Phase Shift Curve.

Now consider a transmission system in which the phase shift per unit length at any frequency f is defined by the curve of Figure 2.

When ω changes to $\omega+d\omega$, the wave length changes from

$$\lambda = \frac{2\pi}{\alpha} \dots\dots\dots\dots\dots\dots (3)$$

to

$$\lambda + d\lambda = \frac{2\pi}{\alpha + d\alpha} \dots\dots\dots\dots\dots (4)$$

and the velocity of propagation changes from,

$$V = \frac{\omega}{\alpha} \dots\dots\dots\dots\dots\dots (5)$$

to

$$V + dv = \frac{\omega + d\omega}{\alpha + d\alpha} \dots\dots\dots\dots\dots (6)$$

Subtracting (3) from (4) and (5) from (6)

$$d\lambda = \frac{2\pi}{\alpha+d\alpha} - \frac{2\pi}{\alpha}$$

$$dV = \frac{\omega+d\omega}{\alpha+d\alpha} - \frac{\omega}{\alpha}$$

$$\therefore \frac{dV}{d\lambda} = \frac{\frac{\omega+d\omega}{\alpha+d\alpha} - \frac{\omega}{\alpha}}{\frac{2\pi}{\alpha+d\alpha} - \frac{2\pi}{\alpha}}$$

$$= \frac{\omega}{2\pi} - \frac{d\omega}{d\alpha}\frac{\alpha}{2\pi}$$

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[1] *Vide.* "Hydrodynamics," by Horace Lamb (1895 edition), p. 383; Lord Rayleigh "On Progressive Waves," Proceedings of the London Mathematical Society, 1877, p. 21. Stokes, Smith's Prize Examination, 1876.

So that,

$$\begin{aligned}\gamma &= V - \lambda\frac{dV}{d\lambda}\\ &= \frac{\omega}{\alpha} - \frac{2\pi}{\alpha}\left[\frac{\omega}{2\pi} - \frac{d\omega}{d\alpha}\,\frac{\alpha}{2\pi}\right]\\ &= \frac{\omega}{\alpha} - \frac{\omega}{\alpha} + \frac{d\omega}{d\alpha}\\ &= \frac{d\omega}{d\alpha}\end{aligned}$$

Time of Travel. The time taken by any group envelope to traverse unit length of medium is therefore,

$$t = \frac{1}{\gamma} = \frac{d\alpha}{d\omega}$$

The time taken for the group envelope to traverse l units of the medium is therefore,

$$T = l\frac{d\alpha}{d\omega} = \frac{d(l\alpha)}{d\omega} = \frac{da}{d\omega}$$

if $a = l\alpha$.

Conditions for Freedom from Phase Distortion. If $\frac{a}{\omega}$ is a constant $\frac{da}{d\omega}$ isalso a constant, and each group envelope travels at the same rate and maintains its position with regard to other groups. The form of the original finite wave train is therefore preserved intact. The line OA in Figure 3 represents a system in which such a state of affairs exists.

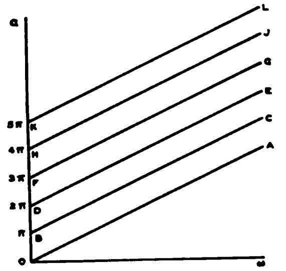

Figure 3—Distortionless Phase Shift Conditions.

The line BC represents a system in which all infinite wave trains are retarded by π in addition to being retarded in proportion to their frequency. It does not require any proof to demonstrate that the effect of this is only to reverse the sense of the received wave; it is in effect equivalent to a single commutation. The lines DE, FG, HJ and KL are respectively equivalent in effect to 2, 3, 4 and 5 commutations. Where the effect is the same as an even number of commutations, the received wave train is indistinguishable from the transmitted wave train, and where the effect is equivalent to an odd number of commutations, reversal of sense occurs.

Effect of Phase Distortion. When $\frac{a}{\omega}$ is not a constant, any finite part of each group envelope traverses the system in the time $\frac{da}{d\omega}$. The minimum value of $\frac{da}{d\omega}$ will be termed t_1. Since all group envelopes outside the finite wave train cancel one another, in the first place only that part of each group will be considered which is initially delimited by the same co-ordinates of space and time as the finite wave train under examination. This is consistent with existing practice. In general, therefore, when a finite wave train is initially applied at the transmitting end of a system, the first appearance at the receiving end occurs at time t_1 after the leading disturbance of the wave train enters the system. Similarly it is immediately evident that the received wave will continue to arrive at least until a time t_2 after the final disturbance of the finite wave train enters the system, where t_2 equals the maximum value of $\frac{da}{d\omega}$ in the pass range of the system. On this basis it is evident that the spreading out or distortion of the original finite wave train is proportional to the value of $t_2 - t_1$.

It has been found convenient to specify the tolerable amount of phase distortion in terms of the value of $t_2 - t_1$. The C. C. I.[1] has laid down that this shall not exceed 30 milliseconds. It is questionable whether this criterion is generally applicable for all types of transmission system, since it discriminates in no way between group envelopes carried by different parts of the frequency spectrum. It is, however, equally valid for all types of circuit having phase shift-frequency curves of the same form as the type of circuit on which it was originally determined by articulation tests—a long distance cable system.

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[1] Comité Consultative International.

Carson[1] has demonstrated that when a steady tone of frequency f is suddenly applied to the input of an uncompensated cable circuit, the wave builds up to one-third its final value at the receiving end after a time $= \frac{da}{d\omega}$ for the line at frequency f. The first impulse always reaches the receiving end after time t_1 referred to above. The interval from the time the first impulse arrives at the receiving end to the time the wave attains one-third its final amplitude is referred to as the time of build-up of the wave. Since in an uncompensated circuit $\frac{da}{d\omega}$ always increases with frequency, t_2 referred to above is equal to $\frac{da}{d\omega}$ for the highest frequency transmitted. It follows, therefore, that the 30 milliseconds referred to for the maximum permissible value of $t_2 - t_1$ is also the time of build-up of the highest frequency in the transmitted range. This is only true for circuits in which the dependency of the total phase angle a on frequency is substantially of the form occurring in a loaded cable circuit before phase compensation is applied. It is definitely not true after the application of phase compensation. For this reason all further reference to time of build-up has been omitted from the present account.

A secondary effect of phase distortion which is of comparatively minor importance, arises from the fact, referred to above, that each group envelope is infinite, while the effects considered up to now have only taken account of that part of each group envelope initially defined by the same co-ordinates of space and time as the finite wave train. Before traversing the system, the parts of all group envelopes lying outside the finite wave train, have a zero resultant, owing to their mutual phase relations. It is evident that when these phase relations are destroyed, the resultant will no longer necessarily be zero, and in actuality it never does reach zero, though it reaches a negligible value so quickly that for most practical purposes it may be neglected entirely.

Phase Correction. In Figure 4 the curve OAB represents the relation between phase shift a and the circular frequency ω for a hypothetical circuit. Since $\frac{a}{\omega}$ is not a constant, $\frac{da}{d\omega}$ is not a constant, and phase distortion exists.

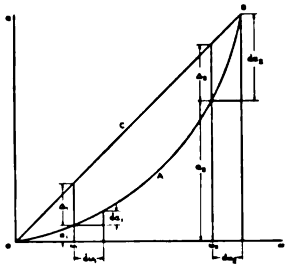

Figure 4—Phase Shift Diagram Illustrating Difference in Time Delay.

It will be assumed that it is not possible to reduce the phase shift of a system, but only to increase it. In such case the straight line OCB represents the phase shift of the distortionless system obtained by adding a minimum amount of phase shift to the system represented by OAB. A very natural error is to assume that the degree of distortion of the system OAB in the range ω_1 to ω_2, is represented by the magnitudes of the frequency ordinates intercepted between the curve OAB and the straight line OCB, eg., by Δ_1 and Δ_2. From what has gone before it is evident that such is not the case, but that with certain reservations the criterion of phase distortion in the range ω_1 to ω_2 is the quantity $\frac{da_2}{d\omega_2} - \frac{da_1}{d\omega_1}$. Its importance in phase correction lies in the fact that it is possible for the corrected curve to lie quite close to a straight line, while owing to the changes in direction of the curve the difference in its slope may be considerable. Especially is this true in long circuits where the phase shift of the highest frequency is large, and the slope of the straight line representing the ideal correction curve is therefore also large.

In the technique of phase compensation it is therefore usual to work only in terms of $\frac{da}{d\omega}$ which is referred to as the time delay, and in what follows time delay and $\frac{da}{d\omega}$ are regarded as being synonymous. It is found in practice, as is to be expected from the above analysis, that time delays in different systems add directly in exactly the same way that attenuations in different systems add, and with identical limitations. For instance, if two symmetrical systems having respectively terminal impedances Z_1 and Z_2 and attenuations (image transfer constants) β_1 and β_2 at any frequency are joined together, the overall attenuation at that frequency will only equal $\beta_1+\beta_2$ if $Z_1=Z_2$, and the systems are correctly terminated at their free ends. Under the above conditions, if the time delays of each system at any frequency are t_1 and t_2 respectively, then the overall time delay at that frequency will be t_1+t_2. If Z_1 does not equal Z_2 then any suitable form of transformer, passive network or amplifier may be used to secure correct impedance matching at the junction of the two systems.

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[1] "The Building-up of Sinusoidal Currents in Long Periodically Loaded Lines." By John R. Carson, Bell System Technical Journal, Vol. III, No. 4, October, 1924, p. 558.

It is evident therefore that if any means exist for producing a system having any required relation between time delay and frequency, such a system may be added to any system in which the time delay varies with frequency in such a way that the overall time delay is independent of frequency. Probably the first system which suggests itself to the mind is a succession of reactive shunt and series elements. This possesses the disadvantage that its attenuation is liable to vary with frequency in an undesirable way, so that equalising networks, and probably extra amplifiers, must be added to compensate for the unwanted attenuation. Fortunately, there exists a type of structure which is capable of affording phase shift without attenuation, the lattice network, of which the two types normally used are shown in Figures 3 to 8 of the succeeding paper which discusses their design.

It will be noted that the "A" type networks contain half as many elements as the "B" type networks, and for purposes of cost computation, it is customary to work in terms of a unit type section which equals one A network or half a B network.

In general, a number of networks are inserted in cascade to form one delay network. For one hundred miles of medium heavy loaded cable (cut-off = 2,860 cycles) compensated to 2,400 cycles, between 50 and 60 unit type sections are necessary if the speech currents traverse the delay network only once.

By an arrangement due to Nyquist it is possible to cause the speech currents to traverse the same delay network twice so that the delay of the network is effectively doubled and only half as many unit type sections are required. The circuit is shown in Figure 5. The incoming currents are applied to one pair of opposite corners (1 and 2) of a Wheatstone Bridge, the four arms of which contain respectively the input to the delay network and three resistances Z_0 equal to the characteristic impedance of the delay network. The far end of the delay network may be left open or may be short-circuited. The outgoing circuit is connected to the other pair of opposite corners (3 and 4) of the bridge. A hybrid coil may be substituted for the bridge, when the same principles apply. Since the bridge is in balance for all instantaneous currents, at the moment any voltage occurs across 1 and 2 there is no voltage across 3 and 4, and no current flows into the outgoing circuit. A voltage, however, does occur across the terminals 2 and 3, the input to the delay network, and currents traverse the delay network in the direction of the arrow. On reaching the open (or short-circuited) end of the delay network, the currents are reflected and cause currents to circulate the bridge mesh, and equal voltages to appear across the terminals 1 and 2, and 3 and 4. In this way currents are supplied to the outgoing circuit, delayed by twice the delay of the network and attenuated uniformly by the bridge circuit. Provided the impedance of the incoming and outgoing circuits are each adjusted to Z_0, no further reflection occurs. The difficulty in the way of employing this circuit lies in the necessity for constructing the elements of the

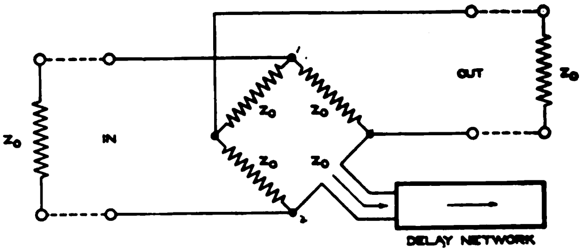

Figure 5—Nyquist Reflection Circuit.

delay network to very close limits, and on this account it is not certain that its use could be justified on a commercial scale. It has, however, been found invaluable for experimental purposes.

So many curves illustrating phase distortion and its correction have been shown from time to time that it is proposed to show here only a few typical results which serve to demonstrate the principles oulined above, and which possess a certain novelty by virtue of their imperfections.

In Figure 6 is shown a measured curve of time delay taken on two hundred miles of medium heavy loaded cable (cut-off = 2,860 cycles) and also the compensated curve of time delay obtained by adding networks as found necessary by calculation of the line time delay from the line constants (i.e., the networks were constructed before any measurements had been made on the line). The delay curve of the networks alone is shown in Figure 7, and it is interesting to note how nearly its ordinates added to the ordinates of the lower curve of Figure 6 give the ordinates of the upper curve of the latter. The irregularities on the time delay curve are due to minor reflections caused by irregularities in the elements of the delay network, the Nyquist reflection circuit having been employed to economise in the number of networks used. A delay curve taken straight through the same set of networks without the reflection circuit is completely free from any trace of these irregularities. The top curve in Figure 6 represents over compensation, and, by removing networks, the time delay curve of Figure 8 was obtained.

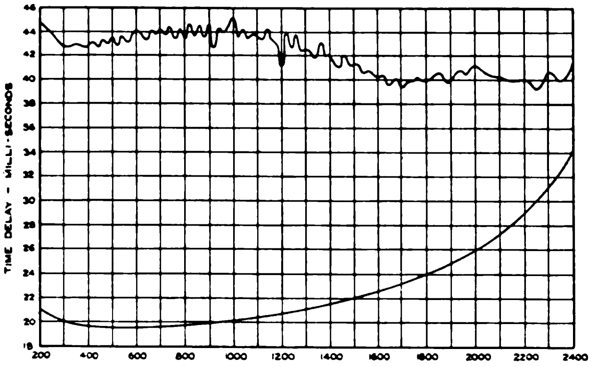

Figure 6—Time Delay Curve on Two Hundred Miles of Medium Heavy Cable Circuit and Corrected Time Delay (First Attempt).

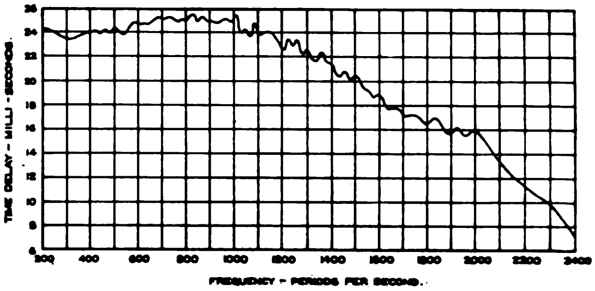

Figure 7—Time Delay Curve of Correcting Network Alone (First Attempt).

The deviation over the range is now reduced from 14 milliseconds to 3 milliseconds. Owing to the multitude of small steep changes in time delay, which correspond to a number of resonances with small damping, such a system does not represent a distortionless one. When a finite wave train is transmitted there is a tendency for the wave to continue in a reduced but constant amplitude after the proper duration of the wave train has expired. One of the best practical results obtained is shown in Figure 9, the frequency of the intermittently applied wave being 2,000 cycles. The bottom oscillogram is the input voltage, the middle oscillogram is the voltage at the output of the uncompensated line, and the top curve is the voltage resulting at the output of the compensating networks, i.e., after the wave has traversed both line and compensating networks.

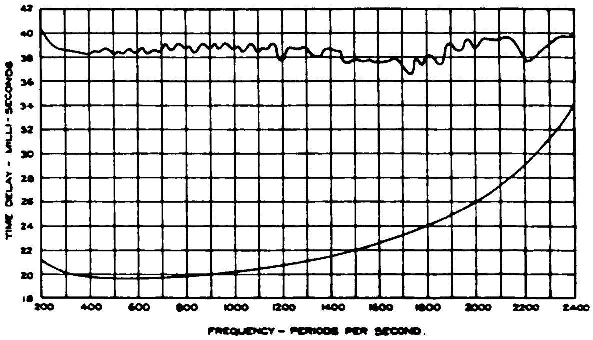

Figure 8—Overall Time Delay Curve of Line and Corrected Time Delay. (Second Attempt.)

From the above, it is evident that the technique of phase compensation is subordinate to a comparatively simple theory, and that its successful practice depends largely on the design of appropriate lattice type networks. This is dealt with in the succeeding paper.[1]

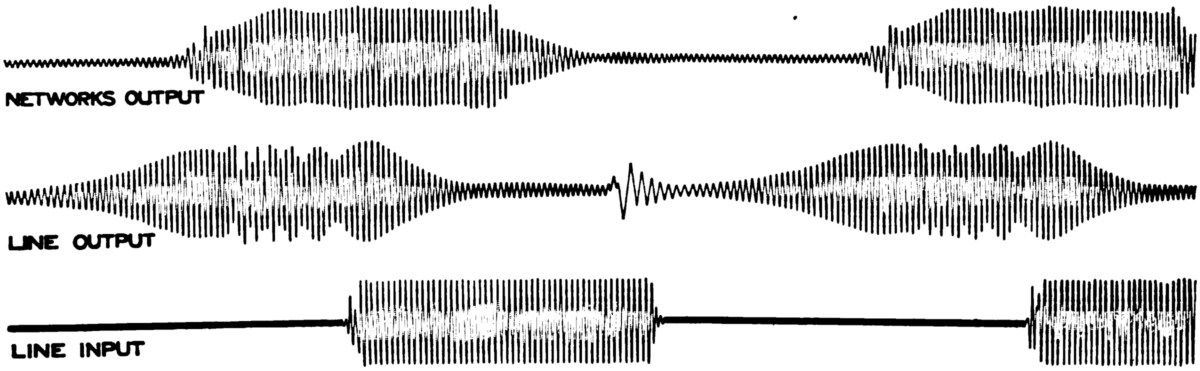

Figure 9—Oscillogram Showing Effect of Phase Distortion and Phase Compensation.

Economic Aspects. The economic aspect of phase compensation involves a series of interacting factors in different fields embracing the whole scope of the telephone art. If these factors were capable of being expressed as mutually comparable functions of determinable quantities, the problem would be simplified but still difficult. Actually such is not the case. Superficially, phase compensation enables a circuit with a relatively low cut-off frequency—and therefore *a priori* with relatively heavy loading, low attenuation and low repeater cost—to give the same performance on transients as a high cut-off circuit, having by the same reasoning high repeater cost. If the cost of phase compensation is less than the difference in cost between the high cut-off circuit, and low cut-off circuit, phase compensation would appear to be desirable. This reasoning quite neglects the fact that the high cut-off circuit is also a high velocity circuit and that therefore the echo problem does not become acute until a much greater distance is reached than with the low cut-off, low velocity circuit. Further, phase compensation may increase the time of travel by as much as 50% over a large part of the frequency range, and this does not tend to improve the echo problem. The introduction of echo suppressors introduces additional cost and increases maintenance charges. Ideally, some compromise should be arrived at by which the necessary grade of intelligibility is furnished for all lengths of circuit, and the total annual charges are a minimum. The process of arriving at this result involves not only the additional considerations of repeater spacing, repeater amplification, and cross talk, but also the size of conductor and the cable lay up, as well as, most important of all, the frequency of occurrence of circuits of different lengths.

Long distance circuits run in the same cable systems as short ones. Where conflict occurs, the economic requirements of the much more common short circuits must be satisfied most completely in the final compromise, unless a very motleyed arrangement is to be tolerated.

Phase distortion is largely a result of lumped loading. Compensation would not be necessary on extra light loaded circuits, if the loading were continuous, for any realisable European circuit. Hence another factor must be considered in the field of application of phase compensation.

The exact place of phase compensation is difficult to assess, since in every case the best performance is furnished by a non-phase compensated circuit. Its introduction into commercial use appears to depend entirely on whether it can be made so cheap that the low price of the circuit using it will render relatively poorer performance tolerable.

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[1] Phase Compensation (II). Design of Phase Compensating Networks, by A.A. Rendall.

Phase Compensation (II)
Design of Phase Compensating Networks

By A. R. A. RENDALL

European Engineering Department, International Standard Electric Corporation

FROM the principles demonstrated in the previous paper it follows that the determining factor in the consideration of phase distortion and its correction, is $\frac{da}{d\omega}$. It is the object of this paper to deduce $\frac{da}{d\omega}$ for the networks most commonly used for phase compensation. The formulæ are derived by the elementary manipulation of circuit equations.

As the first step it is necessary to know the value of $\frac{da}{d\omega}$ for the structure to be compensated over the band of frequencies efficiently transmitted. This data may be obtained either by measurement or computation. A subsequent paper describes a method of measuring $\frac{da}{d\omega}$, and an appendix to this article gives the calculation of this quantity for a loaded line of the type commonly used for long distance telephony.

Any network used for phase compensation must satisfy the following conditions:

1. The characteristics of the network must be such that a time delay frequency characteristic complementary to that of the line may be obtained.
2. The attenuation due to the network should be as small as possible and unifom over the frequency range. Networks can, of course, be designed that will equalise the cable circuit both for phase and attenuation, but this is a complication which will not be dealt with here.

The type of network which has been found most suitable for this purpose is the so-called lattice structure, shown in Figure 1.

This structure and its equivalent forms fulfill the conditions laid down. As will be shown, provided Z_1 and Z_2 are inverse networks, i.e., $Z_1Z_2 = Z_R^2$, and each are pure reactances, the iterative impedance of the structure is a pure resistance and its attenuation is zero throughout the frequency range. When the elements are dissipative, as they must be in practice, the characteristics depart from the ideal, but not by amounts large enough to cause any serious departure from their theoretical performance.

The system of Figure 1 may be replaced by that of Figure 2.

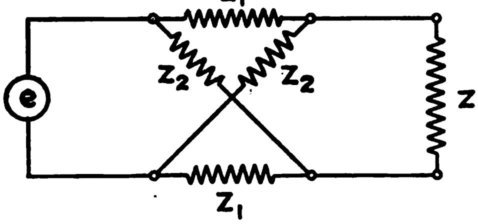

Figure 1—Lattice Network.

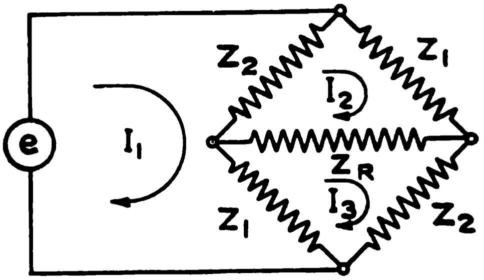

Figure 2—Lattice Network—Bridge Form.

Writing down the equations for the meshes:

$$e = (I_1 - I_2)\ Z_2 + (I_1 - I_3)\ Z_1 \qquad (1)$$

$$0 = I_2\ Z_1 + (I_2 - I_3)\ Z_R + (I_2 - I_1)\ Z_2 \qquad (2)$$

$$0 = I_3\ Z_2 + (I_3 - I_2)\ Z_R + (I_3 - I_1)\ Z_1 \qquad (3)$$

Hence,

$$e = I_1\ (Z_1 + Z_2) - I_2\ Z_2 - I_3\ Z_1 \qquad (4)$$

$$0 = -I_1\ Z_2 + I_2\ (Z_1 + Z_2 + Z_R) - I_3\ Z_R \qquad (5)$$

$$0 = -I_1\ Z_1 - I_2\ Z_R + I_3 (Z_1 + Z_2 + Z_R) \qquad (6)$$

Adding equations (2) and (3) we get:

$$0 = -I_1\ (Z_1 + Z_2) + I_2\ (Z_1 + Z_2) + I_3\ (Z_1 + Z_2) \qquad (7)$$

Consider first the case when Z_1+Z_2 is not equal to 0,

then

$$I_1=I_2+I_3 \tag{8}$$

Substituting in (4) and (5) we get:

$$e=I_1\, Z_2+I_2\,(Z_1-Z_2) \tag{9}$$

$$0=-I_1\,(Z_2+R)+I_2\,(Z_1+Z_2+Z_R) \tag{10}$$

Eliminating I_2 and substituting Z_R^2 for $Z_1\, Z_2$

$$e\,(Z_1+Z_2+2Z_R)=I_1\,(Z_R\, Z_2+Z_R Z_1+2Z_R^2) \tag{11}$$

$$e=I_1\, Z_R$$

or

$$\frac{e}{I_1}=Z_0=Z_R \tag{12}$$

Where Z_0 is the input impedance of the network.

Substituting for I_1 in (9):

$$e=\frac{e}{Z_R}Z_2+I_2\,(Z_1-Z_2) \tag{13}$$

from which

$$I_2=e\frac{Z_R-Z_2}{Z_R(Z_1-Z_2)} \tag{14}$$

$$I_3=(I_1-I_2) \text{ from equation (8)} \tag{15}$$

$$=e\frac{Z_1-Z_R}{Z_R(Z_1-Z_2)} \tag{16}$$

Current in $Z_R=I_R=I_2-I_3$

$$=e\frac{Z_1+Z_2-2Z_R}{Z_R(Z_1-Z_2)} \tag{17}$$

∴ Current ratio

$$=\frac{I_1}{I_R}=\frac{Z_1-Z_2}{Z_1+Z_2-2Z_R} \tag{18}$$

Now $Z_1\, Z_2=Z_R$.

$$\text{Therefore } \frac{I_1}{I_R}=\frac{(\sqrt{Z_1}-\sqrt{Z_2})\,(\sqrt{Z_1}+\sqrt{Z_2})}{(\sqrt{Z_1}-\sqrt{Z_2})^2}$$

$$=\frac{(\sqrt{Z_1}+\sqrt{Z_2})}{(\sqrt{Z_1}-\sqrt{Z_2})}$$

on multiplying top and bottom by

$$(\sqrt{Z_1}+\sqrt{Z_2})$$

$$\frac{I_1}{I_R}=\frac{(Z_1+Z_2+2Z_R)}{Z_1-Z_2} \tag{19}$$

Now if Z_1 and Z_2 are pure reactances, let $Z_1=jX_1$ and $Z_2=jX_2$ such that

$$\sqrt{X_1\, X_2}=Z_R=K.$$

$$\text{Hence, } \frac{I_1}{I_R}=\frac{j(X_1-X_2)+2K}{j(X_1+X_2)} \tag{20}$$

$$=\frac{(X_2-X_1)-2jK}{(X_1+X_2)}$$

Hence (Modulus)^2

$$=\frac{(X_2-X_1)^2-(2jK)^2}{(X_1+X_2)^2}$$

$$=\frac{(X_2+X_1)^2}{(X_1+X_2)^2}$$

Modulus = 1.

$$\text{Angle of Current Ratio}=\tan^{-1}\frac{2K}{X_2-X_1}$$

$$\text{But } X_2=\frac{K^2}{X_1}$$

$$\therefore \text{ Angle}=\tan^{-1}\frac{2KX_1}{K^2-X_1^2}.$$

Hence

$$\frac{I_1}{I_R}=1\,\underline{\left|\tan^{-1}\frac{2KX_1}{K^2-X_1^2}\right.} \tag{21}$$

$$=1\,\underline{\Bigg/\tan^{-1}\frac{2\frac{X_1}{K}}{1-\frac{X_1^2}{K^2}}} \tag{22}$$

$$=1\,\underline{\big/\,2\tan^{-1}\frac{X_1}{K}}=1\,\underline{/\,\alpha} \tag{23}$$

Where α is the angle through which the current is rotated in passing through the network.

The above reasoning holds for all cases except when $X_1=-jX_2$. However, it may be shown that the final equations hold also for this case.

Case $Z_1+Z_2=0 \quad Z_1=jX \quad Z_2=-jX$

$$X^2=Z_R^2$$

Substitute in equations (4) and (5),

$$e=jXI_2-jXI_1 \tag{24}$$

$$0=jXI_1+Z_RI_2-Z_RI_3 \tag{25}$$

Multiply (24) by Z_r and (25) by jX and subtract

$$\frac{e}{I_1}=\frac{X^2}{Z_R}=Z_R=Z_0 \tag{26}$$

Substituting for X in (25),

$$-jZ_RI_1=Z_R(I_2-I_3)$$

or $$I_1=j(I_2-I_3).$$

Now I_2-I_3 is the current in the output impedance Z_R.

Therefore $$\frac{I_1}{(I_2-I_3)}=j \quad\ldots\ldots\ldots\ldots\ldots\ldots(27)$$

This signifies that the attenuation is zero and that the phase angle is $\frac{\pi}{2}$. Now equation (26) agrees with (12) and putting $X_1=K$ in (23) gives,

$$\frac{I_1}{I_R}=1\,\Big|\underline{\,\frac{\pi}{2}\,}$$

Therefore equation (23) holds for all cases.

From equation (23) the $\frac{d\alpha}{d\omega}$ for the network can readily be derived. It will be noted that as in the previous article $\frac{d\alpha}{d\omega}$ is used to indicate that quantity for unit length, $\frac{da}{d\omega}$ signifies the total $\frac{d\alpha}{d\omega}$ for any length. One section of network is here taken as unit length.

Equation (23),

$$\tan\frac{\alpha}{2}=\frac{X_1}{K}$$

$$\therefore\ \frac{d\alpha}{dX_1}=\frac{\frac{2}{K}}{1+\frac{X_1^2}{K^2}} \quad\ldots\ldots\ldots(28)$$

or $$\frac{d\alpha}{dX_1}=\frac{2K}{K^2+X_1^2} \quad\ldots\ldots\ldots(29)$$

The simplest form of lattice network is that given by an inductance in the series arm and the equivalent inverse network, a condenser, in the cross arms. The only other type of practical importance is that which has resonance in the series arm and a shunt resonance in the cross arms.

The series and cross arms of the networks can be substituted one for the other without affecting the electrical properties of the network. This change may be imagined to be accomplished by a physical twisting of the network. Hence the A type networks, shown in Figure 3, 4, and 5 are mutually equivalent forms as are also the B type networks of Figures 6, 7, and 8.

Throughout this discussion the single element networks of Figures 3, 4, and 5 will be designated A type and the two element networks of Figures 6, 7, and 8, B type.

A Type Networks.

$$Z_1=jX_1=j\omega L \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(30)$$

$$Z_2=jX_2=\frac{1}{j\omega C} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(31)$$

Now $\sqrt{Z_1Z_2}$ must equal K for all frequencies. This is accomplished in this case if $\sqrt{\frac{L}{C}}=K$.

From (29),

$$\frac{d\alpha}{dX_1}=\frac{2K}{K^2+X_1^2}$$

From (30),

$$\frac{dX_1}{d\omega}=L.$$

$$\therefore\ \frac{d\alpha}{d\omega}=\frac{2KL}{K^2+\omega^2L^2} \quad\ldots\ldots\ldots\ldots\ldots\ldots(32)$$

It will be noted that L and K completely define the A type section.

Figure 9 gives a family of curves relating $\frac{d\alpha}{d\omega}$ to frequency for different values of L, assuming K = 700 ohms.

B Type Networks.

$$Z_1=jX_1=\frac{1-\omega^2L_1C_1}{j\omega C_1} \quad\ldots\ldots\ldots\ldots\ldots(33)$$

$$Z_2=-jX_2=\frac{j\omega L_2}{1-\omega^2L_2C_2} \quad\ldots\ldots\ldots\ldots\ldots(34)$$

If the resonant frequency for the series and cross arms is the same then,

$$L_1\,C_1=L_2\,C_2 \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(35)$$

and $$Z_2=\frac{j\omega L_2}{1-\omega^2L_1\,C_1} \quad\ldots\ldots\ldots\ldots\ldots\ldots(36)$$

A TYPE

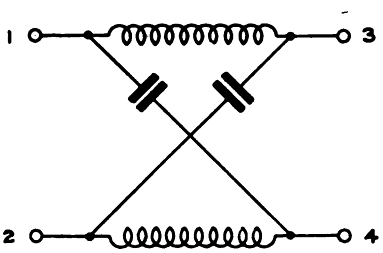

Figure 3—Alternative Forms of A Type Networks.

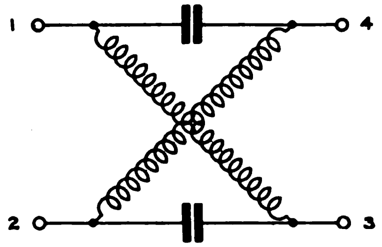

Figure 4—Alternative Forms of A Type Networks.

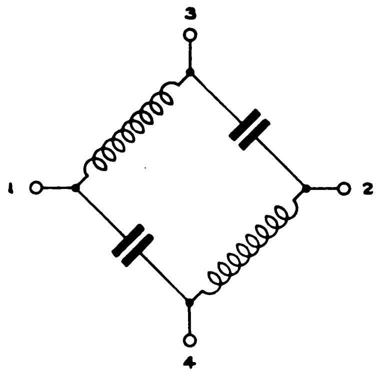

Figure 5—Alternative Forms of A Type Networks.

B TYPE

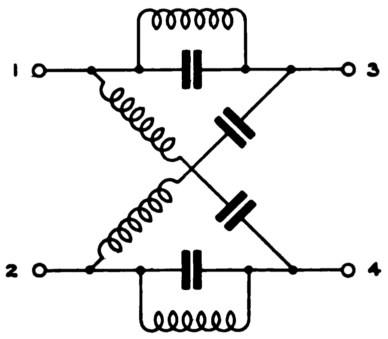

Figure 6—Alternative Forms of B Type Networks.

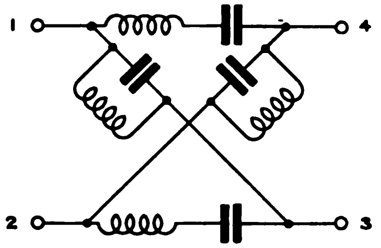

Figure 7—Alternative Forms of B Type Networks.

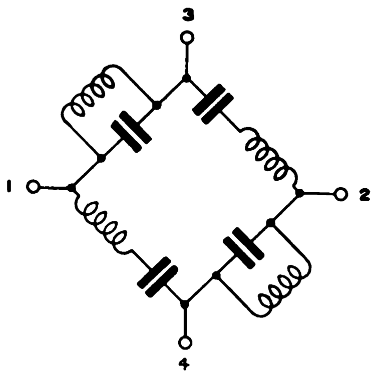

Figure 8—Alternative Forms of B Type Networks.

$$\therefore\ Z_1\,Z_2=\sqrt{\frac{L_2}{C_1}}=\sqrt{\frac{L_1}{C_2}}=K\ \ldots\ldots\ldots\ldots\ (37)$$

If we define the resonant frequency by ω_0 then,

$$\omega_0{}^2\,L_1\,C_1=1\ \ldots\ldots\ldots\ldots\ (38)$$

$$\omega_0{}^2\,L_2\,C_2=1\ \ldots\ldots\ldots\ldots\ (39)$$

$$\text{If }\frac{\omega}{\omega_0}=n\ \ldots\ldots\ldots\ldots\ (40)$$

$$\text{then}\quad \omega^2\,L_1\,C_1=\omega^2\,L_2\,C_2=n^2\ \ldots\ldots\ldots\ldots\ (41)$$

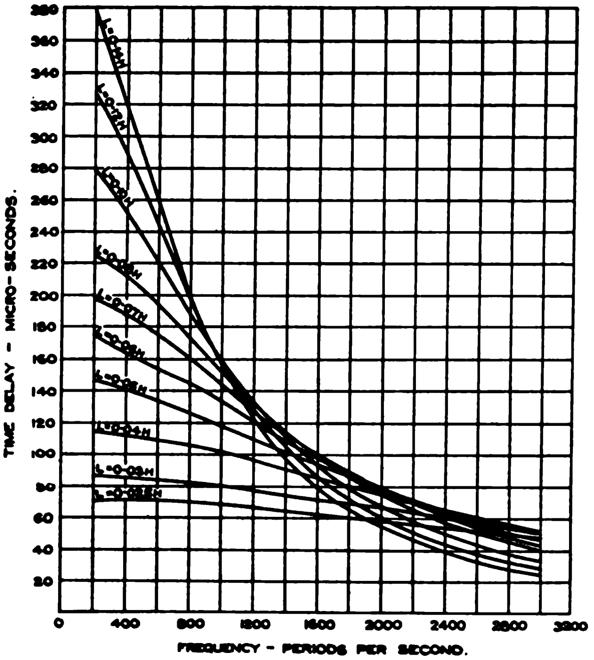

Figure 9—Delay-frequency Characteristic—A Type Networks.

$$\text{From (28)}\ \frac{d\alpha}{dX_1}=\frac{\dfrac{2}{K}}{1+\dfrac{X_1{}^2}{K^2}}\ \ldots\ldots\ldots\ldots\ (42)$$

$$X_1=\omega L_1-\frac{1}{\omega C_1}$$

$$\frac{dX_1}{d\omega}=L_1+\frac{1}{\omega^2 C_1}$$

$$=\frac{\omega^2L_1C_1+1}{\omega^2C_1}\ \ldots\ldots\ldots\ldots\ (43)$$

$$\frac{d\alpha}{d\omega}=\frac{\dfrac{2}{K}\ \dfrac{(\omega^2L_1C_1+1)}{\omega^2\,C_1}}{1+\left[\dfrac{\omega^2L_1C_1-1}{\omega C_1}\right]^2\dfrac{1}{K^2}}\ \ldots\ldots\ (44)$$

$$\frac{d\alpha}{d\omega}=\frac{\dfrac{2}{K}\ \dfrac{\omega^2L_1C_1+1}{\omega^2C_1}}{1+\dfrac{(n^2-1)^2}{\omega^2C_1{}^2K^2}}$$

$$\text{Since } K=\sqrt{\frac{L_2}{C_1}},$$

$$\frac{d\alpha}{d\omega}=\frac{2\sqrt{\dfrac{C_1}{L_2}}.L_1\dfrac{(\omega^2L_1C_1+1)}{\omega^2L_1C_1}}{1+C_1\dfrac{(n^2-1)^2}{\omega^2C_1{}^2L_2}}$$

$$=\frac{2\sqrt{C_1L_1}\sqrt{\dfrac{L_1}{L_2}}\ \dfrac{(n^2+1)}{n^2}}{1+\dfrac{L_1}{L_2}\ \dfrac{(n^2-1)^2}{\omega^2L_1C_1}}$$

$$\text{Let } m=\sqrt{\frac{L_1}{L_2}}\ \text{we get}$$

$$\frac{d\alpha}{d\omega}=\frac{\dfrac{2}{\omega_0}\,m\left(1+\dfrac{1}{n^2}\right)}{1+m^2\dfrac{(n^2-1)^2}{n^2}}\ \ldots\ldots\ldots\ (45)$$

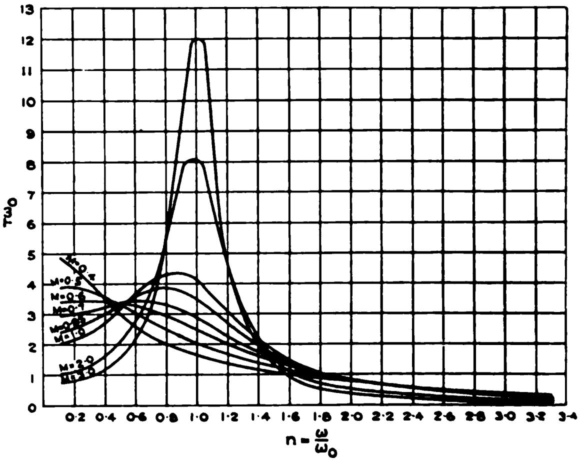

Figure 10—Delay-frequency Characteristic—B Type Networks

It will be seen that K, m, and w_0 completely define the B type networks just as K and L define the A type networks.

Figure 10 plots a family of curves for $\frac{d\alpha}{d\omega}.\,\omega_0$

against n for different values of m. Thus $\frac{d\alpha}{d\omega}$ does not depend upon K but for physical realisation of the network a value must be assigned to this constant, which is the iterative impedance of the network. $\frac{d\alpha}{d\omega}\omega_0$ is plotted for convenience as this quantity depends on m and n only. For any particular network the value of ω_0 is determined by the frequency at which the maximum value of $\frac{d\alpha}{d\omega}$ is required to occur. Dividing the ordinates of the curve by ω_0 gives $\frac{d\alpha}{d\omega}$ in seconds.

Figure 11 shows the typical $\frac{d\alpha}{d\omega}$ curve for a loaded line. It is evident that if networks have to be added to build up this curve to a straight line, then the $\frac{d\alpha}{d\omega}$ characteristic for the compensating networks must be of the form shown on the lower half of Figure 11. It is further evident that by adding certain sections of type A network and others of type B, such a curve could be arrived at. The fitting in of these networks is largely by "cut and try," but experience leads rapidly to a comprehension of the behaviour of the networks.

As an example, the structures designed for the phase correction of the London-Fenny Stratford loop (186 miles M.H.L. circuit) circuit are given.

The particulars of this circuit are as follows:

Loading coil inductance. . = 0.177 henrys.
Loading coil spacing...... = 1.13 miles.
Loading section capacity = 0.07 microfarads.
Cut-off frequency........ = 2,860 cycles/sec.

SUMMARY OF NETWORKS USED

Reference No.	No. of Sections	Type	L_1 Henry	m	f_0
1	32	A	.1 H	....	....
2	16	B	....	.85	1200
3	4	B	....	4	2080
4	4	B	....	3	1700
5	10	B	....	.7	1100
6	1	B	....	2.5	1400

The constants of the B type networks in terms of m, f, and K follow from the definitions of these parameters.

$$C_2 = \frac{m}{\omega_0 K} \qquad L_2 = C_2 \frac{K^2}{m^2} \qquad L_1 = L_2 m^2$$

$$C_1 = \frac{C_2}{m^2}$$

The actual time delay occasioned by these networks can be calculated from equations (42) and (55). In the appendix, the values of time delay shown below are given for the circuit.

The following table illustrates the correction in time delay due to the addition of the networks referred to above.

It will be seen that the delay distortion of the cable circuit has been reduced from 14.5 to 2 milliseconds in the range 400-2,400 p.p.s. by the addition of phase compensating networks. To accomplish this, 32 type A and 35 type B networks were required. Since a type B network contains twice as many components as a type A, and consequently costs twice as much, the expenditure on phase compensation can be conveniently expressed in terms of type A sections, or "unit sections."

Hence 102 unit sections were required to compensate the 186 miles of M.H.L. circuit or

Delay in Milliseconds for Following Frequencies:

System	400	800	1200	1600	2000	2200	2400
32 No. 1 Networks	8.06	6.04	4.24	3.00	2.18	1.92	1.64
16 No. 2 Networks	5.84	7.78	7.26	4.48	2.76	1.92	1.60
4 No. 3 Networks	.16	.26	.50	1.44	3.10	2.32	.78
4 No. 4 Networks	.30	.52	1.24	4.32	1.96	1.08	.64
10 No. 5 Networks	4.52	4.80	3.70	2.24	1.44	1.16	.94
1 No. 6 Networks	.11	.25	.90	.67	.20	.12	.08
186 Miles M.H.L. side	19.5	19.8	20.6	22.50	26.00	29.00	34.00
Total delay	38.49	39.45	38.44	38.65	37.64	37.52	39.68

54 per 100 miles of circuit (approximately a repeater section).

The number of sections required to effect a given degree of phase compensation on any given circuit can be approximately arrived at by calculation.

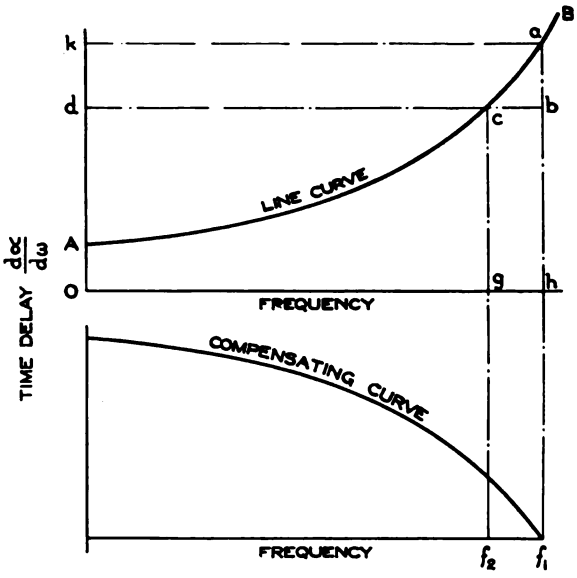

Figure 11—Delay and Compensating Frequency Characteristic for a Lumped Loaded Line.

In Figure 11, AB is the time delay characteristic of the circuit to be corrected. If f_1 is the highest frequency efficiently transmitted then the curve Aa must be built up to ka if the circuit is to be completely equalised for delay. Thus networks must be provided which will fill in the area Aak.

Assume that the circuit need not be absolutely equalised but that some phase distortion t is admissible. Let ab equal t, and then let perpendiculars bd, bh and cg be drawn. Then if we phase compensate so that the ordinates are built up to the line cd, the amount of distortion will be ab, the permissible margin, up to the frequency f_1. Compensation will be complete up to some frequency f_2, less than f_1. Consequently, the actual effect of the permitted distortion is that compensation has to be carried to a lower frequency f_2 which can be described as the effective frequency limit of compensation. In this case the area Acd is that to be compensated.

If the actual area contributed by each network is considered, the number of networks necessary to effect the desired compensation can be determined.

Take the time delay curve $\frac{d\alpha}{da\omega}$ for a type A or B network and deduce the total area under the curve obtained by plotting $\frac{d\alpha}{d\omega}$ against ω, then

$$\text{Area} = \left[\frac{d\alpha}{d\omega}\, d\omega \right]_{\omega=\infty}^{\omega=0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (46)$$

$$= \Big| \alpha \Big|_{\omega=\infty}^{\omega=0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (47)$$

From equation (23),

$$\alpha = 2 \tan^{-1} \frac{X_1}{K}$$

For a type A section $X_1 = \omega L$,

$$\therefore \alpha = 2 \tan^{-1} \frac{\omega L}{K}$$

$$\therefore \text{Area} = \Big| 2 \tan^{-1} \frac{\omega L}{K} \Big|_{\omega=\infty}^{\omega=0}$$

$$\text{Area} = \pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (48)$$

For a type B network,

$$\alpha = 2 \tan^{-1} \frac{X_1}{K}$$

$$X_1 = \frac{\omega L_1}{1 - \omega^2 L_1 C_1}$$

$$\therefore \text{Area} = \Big| 2 \tan^{-1} \frac{\omega L_1}{1 - \omega^2 LC} \Big|_{\omega=\infty}^{\omega=0} \quad \ldots\ldots (49)$$

$$= \Big| 2 \cot^{-1} \left(\frac{1}{\omega L} - \omega C \right) \Big|_{\omega=\infty}^{\omega=0} \quad \ldots\ldots (50)$$

if $\omega = 0$ area $= 2 \cot^{-1} \infty = 0$

if $\omega = \infty$ area $= 2 \cot^{-1} - \infty = 2\pi$

$$\therefore \text{Area} = 2\pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (51)$$

Hence the type B section provides twice the area that a type A provides, and consequently in this sense also one type B equals 2 type A networks, or 2 unit networks. Thus for compensating a given delay curve, that is, filling in a certain area over a delay-frequency curve, type A sections alone can be considered as regards number and cost.

It now remains to determine the actual value of the areas Aak and Acd shown on Figure 11.

Suppose that a phase distortion of 30 milliseconds is permissible, as recommended by the C. C. I. In the appendix it is shown that for any loaded line of cut-off ω_c, the time delay per loading section is given by,

$$\frac{d\alpha}{d\omega}=\omega_c\sqrt{1-r_1^2}\ldots\ldots\ldots\ldots(52)$$

where $r_1=\dfrac{2\pi f_1}{\omega_c}$.

Hence referring to Figure 11,

$$ah=\frac{2}{\omega_c\sqrt{1-r_1^2}}\ldots\ldots\ldots\ldots\ldots\ldots(53)$$

$$cg=\frac{2}{\omega_c\sqrt{1-r_2^2}}$$

$$\text{where}\quad r_1=\frac{2\pi f_1}{\omega_0},\quad r_2=\frac{2\pi f_2}{\omega_0}\ldots\ldots\ldots\ldots(54)$$

$$\therefore\ \frac{2}{\omega_c\sqrt{1-r^2}}-\frac{2}{\omega_c\sqrt{1-r_2^2}}=30\times10^{-3}$$

$$\therefore\ \frac{1}{\sqrt{1-r_2^2}}=\frac{1}{\sqrt{1-r_1^2}}-\omega_c\,15\times10^{-3}\ldots(55)$$

For any given circuit ω_c, the cut-off frequency and f_1 the highest frequency efficiently transmitted are known, hence r_2 can be obtained from (55).

The area to be compensated = Acd = Ogcd − ogcA.

Area ogcA is the area under the $\dfrac{d\alpha}{d\omega}$ curve for the loaded line up to a frequency f_2 (circular frequency ω_2), i.e.,

$$\text{Area ogcA}=\Big|\,\alpha\,\Big|_{\omega_2}^{0}$$

From equation (74) of the appendix and the following,

$$\cos\alpha=(1-\frac{\omega^2LC}{2})\ldots\ldots\ldots\ldots\ldots\ldots(56)$$

$$\sin\frac{\alpha}{2}=\frac{\omega\sqrt{LC}}{2}\ldots\ldots\ldots\ldots\ldots\ldots(57)$$

$$\alpha=2\sin^{-1}\frac{\omega\sqrt{LC}}{2}\ldots\ldots\ldots\ldots\ldots(58)$$

where L and C are the circuit constants as defined in the appendix,

$$\text{Area ogcA}=\left|\,2\sin^{-1}\frac{\omega\sqrt{LC}}{2}\,\right|_{\omega_2}^{0}\ldots\ldots\ldots(59)$$

$$=2\sin^{-1}\frac{\omega_2\sqrt{LC}}{2}\text{ per loading section}\ldots\ldots(60)$$

$=2\sin^{-1} r_2$ (see equation (90) of appendix)

$$\text{Area Ogcd}=(\text{value of }\frac{d\alpha}{d\omega}\text{ at }\omega_2)\omega_2$$

$$=\frac{2\omega_2}{\omega_c\sqrt{1-r_2^2}}\text{ per loading section}\ldots\ldots\ldots(61)$$

$$=\frac{2r_2}{\sqrt{1-r_2^2}}\text{ per loading section}\ldots\ldots\ldots\ldots(62)$$

Hence area Acd $=\dfrac{2r_2}{\sqrt{1-r_2^2}}-2\sin^{-1} r_2$ per loading section ....(63)

Hence for any value of r the number of unit type sections can be obtained by dividing this area by π. It will be noted that the area to be compensated depends upon r only. Figure 12 shows a curve relating the number of unit sections required to the value of r. The ratio r, it should be remembered, is the ratio of the highest frequency transmitted, or the highest frequency to which it is desired to phase compensate, to the cut-off frequency of the cable.

The number of sections derived from the above considerations is the theoretical minimum.

Referring back to the practical example, 102 unit sections were required to compensate 164 loading sections up to 2,400 cycles and the cable cut-off was 2,860 cycles per second. Hence r = 0.84.

From Figure 12 the number of unit sections required theoretically = 63. Therefore the "efficiency" of the actual design was 61.5%. This efficiency factor results from the inability to usefully employ the whole of the area provided by the networks for phase compensation. In general an efficiency of about 65% is obtained. Therefore, the theoretical number of unit sections required per loading section as given in Figure 12 should be increased by this factor in order to obtain the number actually required.

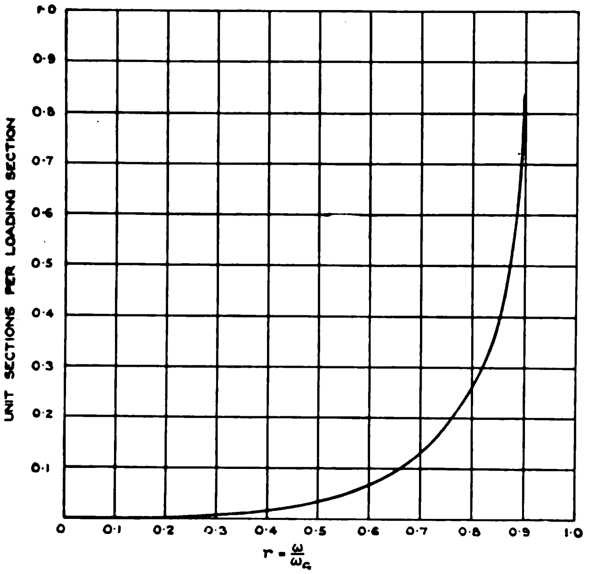

Figure 12—Curve Giving Number of Compensating Sections Required for Phase Equalisation to a Given Fraction of Cut-off.

There are a few points to consider in the actual construction of the networks. Referring to Figure 2 and equations (8), the current flowing in the upper impedance Z_1 is I_2, and in the lower impedance Z_1 is $I_1 - I_3$.

By equation (8) these two currents are equal. Similarly, the currents flowing in both the Z_2 impedances are equal.

Suppose that Z_1 is a pure inductance L, and Z_2 a pure capacity C. Then equations (1) to (3) would be written.

$$e = (I_1 - I_2)\, j\frac{1}{\omega C} + (I_1 - I_3)\, j\omega L \ldots\ldots\ldots\ldots (64)$$

$$0 = I_2\, j\omega L + (I_2 - I_3)\, Z_R + (I_2 - I_1)\, j\omega C \ldots\ldots (65)$$

$$0 = I_3\, \frac{1}{j\omega C} + (I_3 - I_2)\, Z_R + (I_3 - I_2)\, j\omega L \ldots\ldots (66)$$

Now supposing the two inductances L are replaced by two windings on the same core, each winding having a self-inductance L_s, and let the mutual inductance between the winding be M. Consider M to be positive if the current is in the same direction in both windings.

Equations (64) − (66) are then,

$$e = (I_1 - I_2)\, \frac{1}{j\omega C} + (I_1 - I_3)\, j\omega L_s + I_2\, j\omega M$$

$$0 = I_2 j\omega L_s + (I_1 - I_3)\, j\omega M + (I_2 - I_3) Z_R + (I_2 - I_1)\, \frac{1}{j\omega C}$$

$$0 = I_3\, \frac{1}{j\omega C} + (I_3 - I_2)\, Z_R + (I_3 - I_1)\, j\omega L_s - I_2\, j\omega M$$

Since $I_1 - I_3 = I_2$

The equations become,

$$e = (I_1 - I_2)\, \frac{1}{j\omega C} + (I_1 - I_3)\, j\omega\, (L_3 + M) \ldots (67)$$

$$0 = I_2\, j\omega (L_s + M) + (I_2 - I_3)\, Z_R + (I_2 - I_1)\, \frac{1}{j\omega C} . (68)$$

$$0 = I_3 \frac{1}{j\omega C} + (I_3 - I_2) Z_R + (I_3 - I_1)\, j\omega\, (L_s + M) . (69)$$

Hence the equations (67), (68) and (69) are equivalent to equations (64), (65) and (66) if,

$$L_s + M = L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (70)$$

If the coil is taken out of the network and measured, the inductance of the two windings in series aiding, an inductance would be obtained equal to

$$2L_s + 2M \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (71)$$

Hence if the inductance of the two windings in series aiding is made equal to $2L_1$, the condition expressed by equation (70) is satisfied. The same argument can be applied for the type B networks. Hence, the result of practical importance: if the impedance elements Z_1 contain inductance, then the inductances for the two arms need not be separate but can be wound on the same core.

The same applies to the impedance elements Z_2, but of course, inductance elements of Z_2 must not be on the same core as those of Z_1.

It is essential that the impedance elements should be within close limits of the design value, otherwise impedance irregularities will exist between sections and consequently phase and attenuation irregularities will result in the train of sections. In particular it is important that the resonant frequencies of the series and cross arms of the B networks should be as nearly as possible equal.

APPENDIX I.

Calculation of $\frac{d\alpha}{d\omega}$ *for a loaded line.*

A loaded telephone line is essentially a number of recurrent sections, as indicated in Figure 13. Each section consists of distributed capacity, resistance and inductance and in addition lumped inductance. The distributed inductance and resistance may be neglected for the range of frequencies normally transmitted on commercial telephone circuits without serious error.

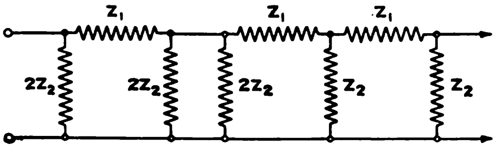

Figure 13—Recurrent Structures Terminated at Mid Shunt.

The problem therefore is to determine the phase constant per section of this network when terminated by an infinite number of similar sections, that is, when terminated by its characteristic impedance.

Let this characteristic impedance be Z_k.

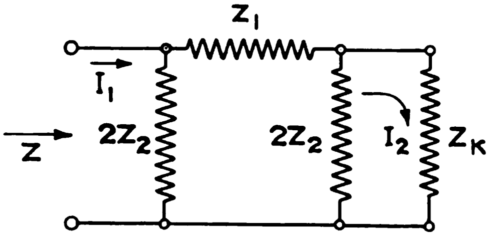

Figure 14—Recurrent Structures Terminated at Mid Shunt.

Then if Z_k is the characteristic impedance $Z=Z_k$.

$$Z=\frac{2Z_2\left[Z_1+\frac{2Z_2Z_k}{2Z_2+Z_k}\right]}{2Z_2+Z_1+\frac{2Z_2Z_k}{2Z_2+Z_k}}=Z_k$$

$$\text{Hence } Z_k=\sqrt{\frac{Z_1Z_2}{1+\frac{1}{4}\frac{Z_1}{Z_2}}}$$

And the current ratio,

$$\frac{I_1}{I_2}=\frac{\frac{Z_1}{2}+Z_2+\sqrt{Z_1Z_2+\frac{Z_1^2}{4}}}{Z_2}\quad\ldots\ldots(72)$$

In the case of the loaded cable, if we neglect resistance, leakance and distributed inductance, the loading section may be represented by the network of Figure 15.

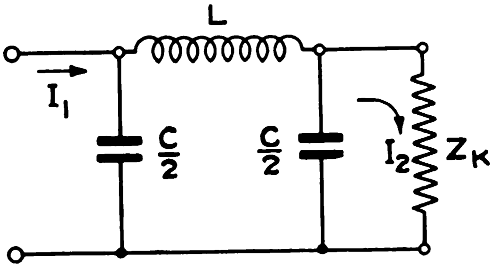

Figure 15—Equivalent Network for a Loading Section with Mid Shunt Termination.

Then at any frequency ω,

$$\frac{I_1}{I_2}=\frac{\frac{j\omega L}{2}-\frac{j}{\omega C}+\sqrt{\frac{L}{C}-\frac{\omega^2L^2}{4}}}{-\frac{j}{\omega C}}$$

$$=\left(-\frac{\omega^2LC}{2}+1\right)+j\omega C\sqrt{\frac{L}{C}-\frac{\omega^2L^2}{4}}\quad\ldots(73)$$

Therefore the phase rotation per loading section is given by,

$$\tan\alpha=\frac{\sqrt{\omega^2LC-\frac{\omega^4L^2C^2}{4}}}{1-\frac{\omega^2LC}{2}}\quad\ldots\ldots(74)$$

$$\text{Now}\qquad\tan\alpha=\frac{\sqrt{1-\cos^2}}{\cos\alpha}$$

Therefore by inspection

$$\cos\alpha=1-\frac{\omega^2LC}{2}$$

$$\therefore-\frac{d\alpha}{d\omega}\sin\alpha=-\omega LC$$

$$\frac{d\alpha}{d\omega}=\frac{\omega LC}{\sin\alpha}$$

$$\sin \alpha = \sqrt{1-\cos^2\alpha} = \omega\sqrt{LC}\sqrt{1-\frac{\omega^2 LC}{4}}$$

$$\therefore \frac{d\alpha}{d\omega} = \frac{\sqrt{LC}}{\sqrt{1-\frac{\omega^2 LC}{4}}} \;\ldots\ldots\ldots\ldots\ldots\ldots (75)$$

Let f_c be the cut-off frequency of the cable, which is defined by:

$$f_c = \frac{1}{\pi\sqrt{LC}} \;\ldots\ldots\ldots\ldots (76)$$

And f be any frequency under consideration.

Also, $\frac{f}{f_c} = r$

hence $\frac{\omega}{\omega_c} = r \;\ldots\ldots\ldots\ldots\ldots\; (77)$

Now from (76), $\omega_c = \frac{2}{\sqrt{LC}} \;\ldots\ldots\ldots\; (78)$

$$\therefore \; \omega_c^2 LC = 4 \;\ldots\ldots\ldots\ldots\ldots (79)$$

Multiplying both sides by $r^2 = \frac{\omega^2}{\omega_c^2}$

we get $\omega^2 LC = 4r^2 \;\ldots\ldots\ldots\; (80)$

Now from (75),

$$\frac{d\alpha}{d\omega} = \frac{\sqrt{LC}}{\sqrt{1-\frac{\omega^2 LC}{4}}}$$

$$= \frac{2}{\omega_c\sqrt{1-r^2}} \text{ per loading section} \;..\; (81)$$

Hence it will be seen that at low frequencies where r^2 is small compared with 1 the delay $\frac{d\alpha}{d\omega}$ is given by $\frac{2}{\omega_c}$. This is true down to frequencies of the order of 200 cycles when the effect of line resistance begins to become apparent. As the frequency increases this delay is multiplied by a factor $\frac{1}{\sqrt{1-r^2}}$.

In Figure 16 are plotted the measured values and calculated values of delay for the following circuit.

London-Fenny Stratford Looped.

Length (186 miles = 299.4 km.)		164 loading sections
Average capacity per load section		.06915 mfd.
Loading coil inductance		.177 henry
Loading section inductance		.001 henry
Cut-off frequency	f_c	2,860 p.p.s.
	w_c	18,000 p.p.s.

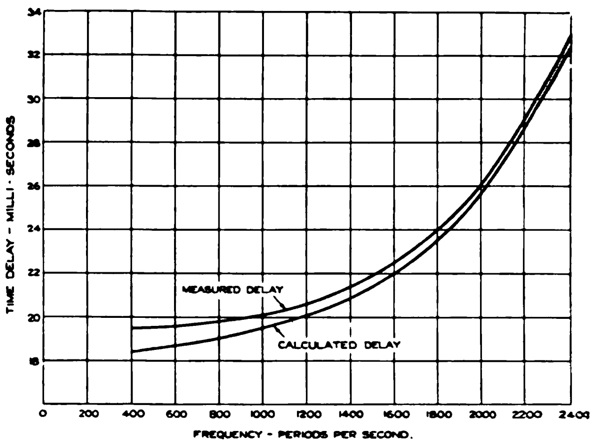

Figure 16—Measured and Calculated Delay Frequency Characteristics for an Actual Loaded Circuit.

Frequency	$r = f/f_c$	Calculated Delay milliseconds	Measured Delay milliseconds
400	.14	18.4	19.5
800	.28	19.0	19.8
1200	.42	20.1	20.6
1600	.56	22.0	22.5
2000	.70	25.6	26
2200	.77	28.5	29
2400	.84	33.6	34

It will be observed that the measured delay exceeds the calculated delay by an increasing amount as the frequency is reduced. This excess delay is due to repeating coils and repeaters in the actual line, which have not been considered in the calculation of delay.

Hence at the lower frequencies of the voice range where r^2 is small compared with 1 the delay $\frac{d\alpha}{d\omega}$ is $\frac{2}{\omega_c}$. This is true down to about 200 p.p.s. for medium heavy loaded circuits; below this value conductor resistance is of importance and the assumptions made are not valid.

The value $\frac{2}{\omega_c}$ written in another form $\sqrt{LC}$ is the smooth line time delay per unit length or $\frac{1}{\sqrt{LC}}$ is the smooth line velocity.

The effect of the lump loading is to multiply this delay $\sqrt{LC}$ by a factor $\frac{1}{\sqrt{1-r^2}}$. It is interesting to compare this quantity with the mid section impedance of a loaded line. On the same assumptions as made above $Z_k=\sqrt{\frac{L}{C}}\frac{1}{\sqrt{1-r^2}}$.

Hence, again, $\sqrt{\frac{L}{C}}$ is the smooth line impedance (neglecting resistance and leakance) and $\frac{1}{\sqrt{1-r^2}}$ is the factor due to the "lumped" loading.

Phase Compensation (III)

The Nyquist Method of Measuring Time Delay $\frac{da}{d\omega}$

By **E. K. SANDEMAN and I. L. TURNBULL**

European Engineering Department, International Standard Electric Corporation

THE Nyquist[1] method of measuring time delay has been used by the authors in the work on phase compensation described in the preceding papers in this issue of *Electrical Communication*. As set up by them it enables precise measurement of time delay to be made at any one frequency in a minute and a half. The limit of accuracy obtainable with the apparatus used corresponded to an error of ±25 microsecond (±0.000025 second). Usually it was not considered necessary to take readings to such small limits.

The method follows logically from the fact that $\frac{da}{d\omega}$ is the rate of travel of the envelope of two frequencies differing from one another by an interval so small that the time delay is a constant over the interval. If the time delay is not a constant over the frequency interval chosen, then the Nyquist method of measuring time delay gives $\frac{\Delta a}{\Delta\omega}$, which is the mean value of $\frac{da}{d\omega}$ over the interval.

Referring to Figure 1, O_1 is an oscillator generating a low frequency f_1. For simplicity f_1 may be considered to be smaller than the value of the frequency change necessary to cause a rotation of 2π through the structure under measurement, though this is not essential to the method. The case where this is not true is dealt with in detail later. 2π f_1 is the value of $d\omega$ by which da is divided to give $\frac{da}{d\omega}$.

O_2 is an oscillator generating a frequency f_2 which determines the frequency at which $\frac{da}{d\omega}$ is to be measured.

f_1 and f_2 are supplied to M_1, which is a balanced modulator suppressing f_1 and delivering to the structure to be measured the products of modulation f_2, f_2+f_1 and f_2-f_1. The modulated f_2 after traversing the structure is demodulated in D_1, which supplies the frequency f_1 to one coil of the air core dynamometer shown. The other coil is supplied with f_1 from the same oscillator O_1, through the phase shifter P and an amplifier A. Where the two ends of the circuit are not at the same place and where no separate channel is available for transmitting f_1, the modulator M_2 and the demodulator D_2 (shown dotted) are used to transmit f_1 over the physical circuit being examined. When the currents in the dynamometer are in quadrature no deflection is

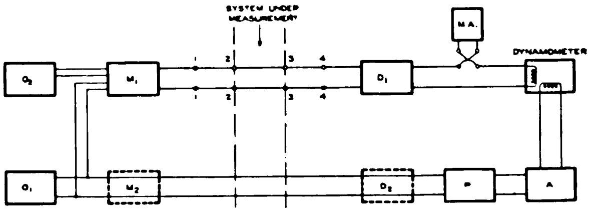

Figure 1—Schematic of Method.

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[1] United States Patent No 1,645,618

obtained; and in practice it is thus possible to detect changes in the phase of the f_1 component of the output of the demodulator with an accuracy depending on how nearly the phase shifter can be read. The dial of the phase shifter is 6½ inches in diameter, which means that without a vernier it is easily possible to read to an accuracy of ±0.25 degrees of arc. If f_1 is 30 cycles, it will appear from what follows that this corresponds to an accuracy of $\pm\frac{0.25}{360\times30}$ seconds. By making f_1 larger, a greater accuracy is obtainable, but as this increases the value of $d\omega$, it is not always a permissible expedient. It should be mentioned that with a departure from quadrature of 0.25 degrees the dynamometer gives an easily readable deflection with a dissipation in each of its coils, of 50 milliwatts, which is the power conveniently obtainable in practice. It is necessary to use an air core dynamometer in order to avoid changes of zero with change of current amplitude.

Method of Measurement. The structure is removed and a resistance attenuating structure is inserted between terminals 1,1 and 4,4. If the ends of the system 2,2 to 3,3 are widely separated, this step must be completed before the parts of the apparatus are sent to their respective ends of the circuit. Suitable values of f_1 and f_2 are chosen, and the phase shifter P adjusted until the currents in the dynamometer coils are in quadrature; θ_1, the angle of phase shift contributed by the phase shifter, is then read off. The structure to be measured is then inserted, and the phase shifter adjusted until the currents in the dynamometer are again in quadrature; the angle on the phase shifter is then θ_2.

$$\text{Then } \frac{da}{d\omega} = \frac{\theta_2-\theta_1}{360^\circ \times f_1}, \text{ if } \theta_2 \text{ and } \theta_1 \text{ are in degrees}$$

$$= \frac{\theta_2-\theta_1}{2\pi f_1}, \text{ if } \theta_2 \text{ and } \theta_1 \text{ are in radians.}$$

Proof. θ_2 and θ_1 are read off the phase shifter in degrees. The first formula will now be proved; the second follows from the first by multiplying numerator and denominator by $\frac{2\pi}{360}$.

The output from Modulator M_1 consists of a wave having a frequency f_2 whose amplitude varies sinusoidally at a frequency f_1 (Figure 2). The envelope of the wave of frequency f_2 is therefore two sine waves, as is well known to those familiar with the process of modulation. From the introductory article on phase compensation in this issue, it follows that any identified part of this envelope traverses the system 2,2 to 3,3 in a time $t=\frac{da}{d\omega}$.

The number of complete wave envelopes, or wave groups, in the system 2,2 to 3,3 at any moment is therefore $f_1\times t$. On detection the output wave of frequency f_1 from the modulator D_1 is in phase with the envelope wave form entering D_1. The change of phase of the output wave of frequency f_1 from D_1, because of the system, is therefore

$$\theta_2-\theta_1=360\, f_1 t$$

$$\therefore t=\frac{da}{d\omega}=\frac{\theta_2-\theta_1}{360\, f_1}.$$

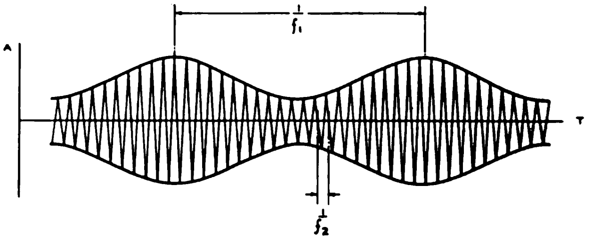

Figure 2—Modulated Wave.

By writing down all the equations for the processes of modulation and demodulation, the same answer is obtained. It is considered, however, that the above proof is sufficiently rigid in itself.

The only component of the practical system calling for comment is the phase shifter. This contains two fixed coils at right angles in space, supplied by the oscillator O_1 with equal alternating currents of frequency f_1, made permanently in quadrature by the use of a capacity and a resistance respectively in series with each coil. A third coil rotating about the common diameter of the two fixed coils therefore receives a current which varies in phase directly with its angular position in space. This type of phase shifter is capable of introducing a phase change of any value between 0 and 360°.

The accuracy of any measurement, apart from the limits of observational error given above as

±25 microseconds, depends only on the accuracy with which the value of the frequency f_1 is known.

The determination of an initial setting for the phase shifter, with a 700 ohm resistance line between terminals 1,1 and 4,4 eliminates any errors through time delay in the apparatus itself. This, incidentally, is less than a millisecond, and negligible for most purposes. The output circuit and transformer of the modulator, and the input transformer of the demodulator, present impedances to the structure under measurement which are identical with the corresponding impedances of a four wire repeater. The use of the above method of measurement, therefore, arbitrarily defines the time delay of any structure measured as the difference in time delay observed when a 700 ohm resistance line is inserted between 1,1 and 4,4, and when the structure under examination is inserted between 1,1 and 4,4. Any time delay introduced as a consequence of the departure of the terminal impedance of the structure from a pure resistance of 700 ohms is regarded as part of the time delay of the structure. The importance of this is generally small, but the statement of the principle assists to clarity of thought.

Consideration shows that two positions of the phase shifter can always be found which will give a balance on the dynamometer, one being 180° away from the other. These positions may be distinguished from one another by the fact that if the phase shifter handle be rotated clockwise, the dynamometer needle will move to the right at one balance position, and to the left at the other balance position of the phase shifter. It is, of course, essential that corresponding balance points should be obtained for the two readings—(a) resistance line in circuit, (b) the structure under measurement in circuit. To avoid confusion it has become the practice to accept a balance only if the dynamometer needle moves to the right when the phase shifter handle is rotated clockwise.

The most common value for f_1 is 30 cycles, when the delay is so small that the difference between the two phase shifter readings taken as above is not sufficient to reduce the percentage error to a reasonable value, the low frequency may be increased up to, say, 100 cycles. This will necessitate readjusting the condenser and resistance in series with the phase shifter coils, and will make one revolution of the phase shifter correspond to a time delay of 10 instead of 33.3 milliseconds. A time delay of 1 millisecond will then correspond to 36° instead of 11° with a corresponding reduction in observation error. In Figure 3 is shown a time delay measurement on an element of a constant delay network having a delay of approximately one millisecond.

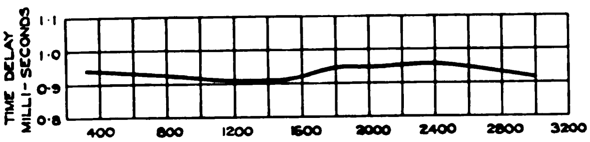

Figure 3—Delay Measurement on Constant Delay Network.

When a long line or a network having a very considerable delay (e.g., 100 milliseconds), is measured, if $f_1 = 30$ cycles, then the position of the phase shifter at balance represents approximately three whole revolutions. If the approximate time delay is known, no difficulty arises; otherwise an absolute reading of time delay cannot be obtained, as the number of rotations of the phase shifter is not known. A way of overcoming this difficulty is to use a very low frequency, say, 1 cycle, for which one revolution of the phase shifter corresponds to 1,000 milliseconds. The limitation of the present phase shifter will not permit this procedure. An alternative is to increase the frequency f_1 in a small step, say from 30 cycles to 31 cycles. The phase shifter is then readjusted and a new reading taken. The change in phase shift δ will be one-thirtieth of the previous shift, and provided the phase shift change per cycle in the structure is less than 360° this phase shift change will appear as the rotation of the phase shifter consequent upon changing the frequency from 30 cycles to 31 cycles.

If the true phase shift for 30 cycles is

$$\theta = n.360^\circ + \phi$$

the change in phase shift is

$$\delta = \frac{\theta}{30} = \frac{n.360}{30} + \frac{\phi}{30}$$

so that $n = \dfrac{30\delta - \phi.}{360}$

Example. On testing a line of unknown delay, using 30 cycles, a rotation of 60° on the phase shifter separates the readings taken with and without the line, i.e., $\phi = 60°$. With 31° the corresponding angle is 86°, so that $\phi + \theta = 86°$ and $\theta = 26°$.

$$\therefore n = \frac{30 \times 26 - 60}{360} = 2.$$

Hence the correct reading in the first instance is $60° + 2 \times 360° = 780°$ equivalent to 77.2 milliseconds delay. It is to be noted that n can only be an integer, so that it is not necessary to have abnormal accuracy in the oscillator. Standard oscillators hold their calibration indefinitely to an accuracy of 0.1 per cent.

Even when the value of the delay is known approximately, a little difficulty occurs in deciding which way the phase shifter has moved when the delay is being determined. For instance, with a network having an expected delay of 15 to 18 milliseconds, it is found that the value of ϕ is 170° if the phase shifter has moved in one direction, and $360° - 170° = 190°$ if the phase shifter has moved in the other direction. Which is correct? If the network is easily accessible, the quickest solution is to reduce the number of sections, when the direction of the movement of the rotor of the phase shifter will be immediately obvious from a new time delay measurement. In the case of a line this is not possible. If the sign of $\frac{da}{d\omega}$ is known (for all ordinary lines it is, of course, positive) then the easiest solution is obtained by resetting the high frequency oscillator (O_2) to a different frequency and taking another measurement of delay, when the new position of the rotor will give a clue to which of the two readings is correct. Failing this, recourse is necessary to the method of altering the low frequency as above outlined.

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Page 132, column 2—Substitute a_r/a for a_r in the left hand side of the equation.

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